PERFORMANCE ASSESSMENT OF ONGRADE^{TM} HORIZONTAL DIRECTIONAL DRILLING METHOD

By

REETI R. BURMAN

Bachelor of Engineering in Civil Engineering
University of Mumbai
Mumbai, Maharashtra, India
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PERFORMANCE ASSESSMENT OF ONGRADE^{TM}

HORIZONTAL DIRECTIONAL DRILLING METHOD

Thesis Approved:

Dr. Hyunseok (David) Jeong

Thesis Advisor

Dr. Garold Oberlender

Dr. Rifat Bulut

Dr. A. Gordon Emslie

Dean of the Graduate College

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CHAPTER 1

INTRODUCTION

1.1 Overview

Many existing utility systems are located in congested or urban areas. Installation, rehabilitation, or renewal of these systems using traditional open-cut construction causes significant disruption of traffic and businesses, and leads to unsafe trenches for workers and pedestrians. To reduce the disruptions caused by open-cut construction, the Horizontal Directional Drilling (HDD) method has been widely accepted and used for installing gas and water lines, telecommunication cables, and electrical conduits.

One application where HDD has had only moderate success is in the installation of gravity flow liquid conduits, such as sewer and storm drainage (Gunsaulis et al. 2007). Two primary reasons for this slow acceptance are; 1) Majority of those who operate and plan the construction of gravity sewer and storm drainage systems are not aware that HDD is suitable for many of their projects, and 2) many sewer systems professionals who are aware of directional drilling do not believe that HDD equipment is capable of installing pipes at the critical grades essential for gravity-flow sewer systems (Griffin 2003a).

Figure 1.1 shows that despite the wide range of applications of the HDD method for underground installation, its use for rehabilitation and renewal of water and sewer systems is limited to only 19%. It is important to note that this 19% encompasses the water and sewer (force mains and gravity mains) installations. These percentages give an idea of the limited use of this trenchless method of installation by the sewer industry.

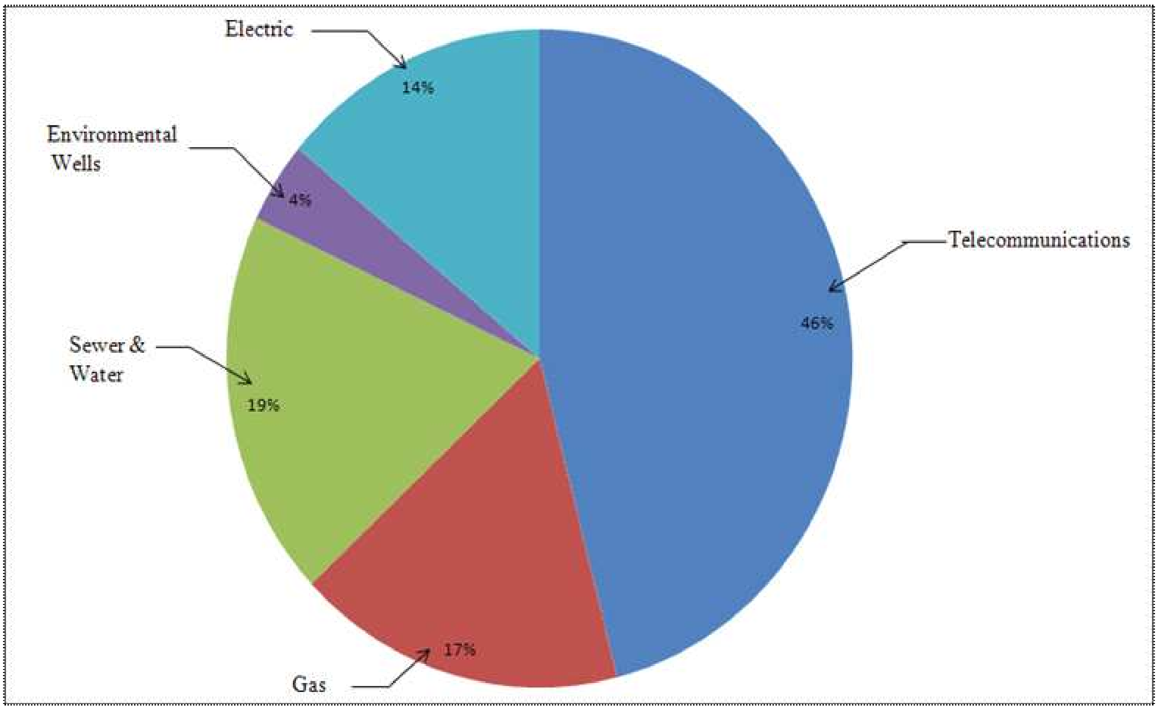


Figure 1.1: Applications for HDD Method [3]

1.2 Problem Statement

However, since the early 2000's there are several trade journal articles that have reported successful applications of HDD to gravity sewer pipeline projects in which shallow grade (sometimes, less than 1% grade) is specified. All of these articles stress that the technical improvement of tracking receiver systems and advanced arrangements are the major factor for HDD to be used to install on-grade pipes. The technology illustrated in U.S. Patent 7,510,029 is a representative technique for accurate identification and tracking of the vertical location of the drilling head.

Also a recent survey conducted by Hashemi and Najafi (2007) indicates that the biggest problems of municipal engineers dealing with deteriorating water and sewer systems are the lack of available funding (79%), lack of available technologies (4%), and lack of information on available technologies (2%). Public works engineers are constantly faced with a situation to do more with less budgeted money. The advancements of new technologies and their accurate performances must be quickly available to municipal engineers, so they can have more options to consider for their future projects.

The OnGrade^{TM} HDD method is a new and technically viable option for constructing gravity sewer pipelines. However, a comprehensive assessment of its technical capabilities and economic feasibilities over the open-cut method is nonexistent. Thus, it is imperative to conduct a reliable assessment of this new technology and to disseminate the findings to engineers and decision makers of gravity sewer installation projects.

1.3 Research Objectives

This study will evaluate the OnGrade^{TM} HDD technology that has been developed by Gunsaulis et al. (2007) in terms of its technical performances and economic feasibilities by quantitatively comparing it with the conventional open-cut method. The main objectives of this research are:

a. To compare and evaluate technical capabilities of the OnGrade^{TM} HDD method with respect to grade accuracy, installed pipe condition, etc. over the open-cut method using actual field test data.

b. To quantitatively measure and compare the costs of implementing both OnGrade^{TM} HDD method and open-cut method. User costs in addition to restoration costs and direct costs shall be considered to obtain a fair comparison.

c. To analyze the conditions under which the OnGrade^{TM} HDD method is most appropriate. Not all conditions are acceptable for this new technology. The boundary conditions and limitations for the technology will be identified and documented.

1.4 Research Methodology

This section discusses the research methodology that was adopted to accomplish the goals and objectives of this research. This research was conducted in four main sections as follows: 1. Literature Review 2. Industry Survey 3. Field Tests, and 4. Cost Analysis and development of the decision support system. Figure 1.2 shows the different elements of each of the above stated sections.

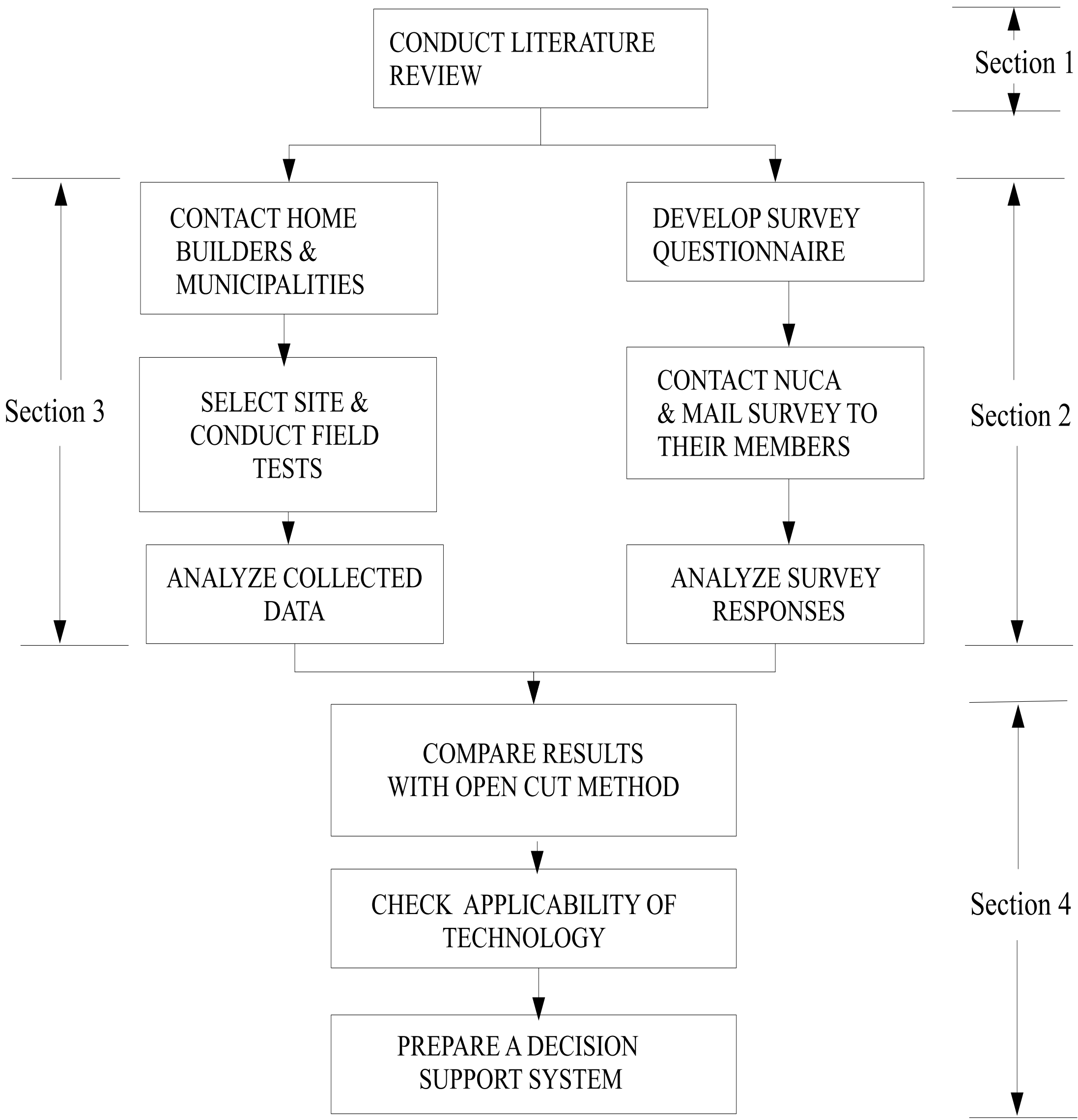


Figure 1.2: Methodology Process Flow Chart

1.4.1 Literature Review

A comprehensive literature review was conducted to identify different research projects which have been completed prior to our study regarding the use of HDD for the installation of gravity sewer lines. The literature review was also focused on understanding the opinions and problems faced by the contractors who have worked with the traditional HDD technology for installing gravity sewer pipes. This enabled better understanding of the factors which needed to be considered for analyzing the applicability of the new OnGrade^{TM} HDD method for gravity sewer installations.

1.4.2 Industry Survey

Based on the information gathered from the literature review and with the guidance of the members associated with this project, a questionnaire was developed. The main objectives of this survey questionnaire are as follows:

a. Identify the perceptions of the industry about traditional HDD technology.

b. Identify the reasons for the slow acceptance of the technology.

c. Identify the benefits, limitations, and boundary conditions of the available technology.

d. Identify the problems faced by the contractors during the application of traditional HDD technology

A nationwide survey was conducted to collect data from a majority of the utility contractors across the country, the National Utility Contractors Association (NUCA) was contacted. NUCA played an important role by distributing the questionnaire among its members. The questionnaires were filled out by members of NUCA, and the data collected was then analyzed.

1.4.3 Field Tests

Field tests were conducted to collect real time data for both the OnGrade^{TM} HDD and the open-cut methods of installation. The following strategy was used to collect the real time data.

a. Various municipalities and home builders in and around the city of Stillwater, Oklahoma were contacted to locate projects which matched the requirements of the research project in terms of grade and time line.

b. After the selection of the site for the field tests, meetings were conducted with the respective city officials to acquire the permissions to progress with the field tests.

c. During the field tests on each project, gravity sewer pipe was installed using the OnGrade^{TM} HDD method.

d. The data collected on site during the installation process included factors like the size of the crew on the job site, type of equipment required, time needed for the installation of per linear foot of the pipe and the problems encountered during the installation process for both the methods of installation under consideration.

1.4.4 Cost Analysis and Development of the Decision Support System

Based on the data collected on the job-site a cost analysis has been done in order to check the economic feasibility of either method of installation. This analysis included calculating the construction costs associated with the use of the OnGrade^{TM} HDD method and the open-cut method. The construction costs calculated included the calculation of the direct costs, restoration costs and social costs associated with any project. Also, based on the data collected a decision tree was developed to help identify the best suited conditions for the application of the OnGrade^{TM} HDD method.

1.5 Organization of this Study

Chapter II provides a summary of different articles, journal papers reviewed to document researches previously conducted on the applications of HDD. Chapter III describes in detail the OnGrade^{TM} HDD method of installation. It introduces the tools and techniques adopted by this method and also describes in detail the step by step process of installation. Chapter IV discusses the formulation of the survey questionnaire that was sent out as a part of this research and analyzes the survey responses in detail. Chapter V evaluates the technical capabilities and also compares the costs associated with the OnGrade^{TM} HDD method to the traditional open-cut method, based on two field trials conducted. Chapter VI outlines the boundary conditions associated with the OnGrade^{TM} HDD method of installation. It describes in detail the effect of each boundary condition on the execution of the project. It also describes an Excel based decision support system developed to facilitate the decision making process of selecting a method for installation of on-grade sewer pipe. Chapter VII concludes this research by summarizing the findings and provides recommendations for future work in this area.

CHAPTER 2

Literature Review

2.1 Overview of Horizontal Directional Drilling

HDD is believed to be the fastest growing segment in the underground trenchless construction industry [5]. Its equipment and installation techniques originated in the oil fields in the 1970s. Ever since, this technology has evolved by merging the technologies available in the utilities and water well industries [6]. During its formative years, HDD had relatively complicated and inaccurate steering and navigation systems, which resulted in a relatively slow acceptance of this method [5]. But with new systems and navigation tools, HDD has proven to be a very cost effective method and an excellent alternative to the traditional open-cut method for the installation of conduits in congested urban areas. HDD has had tremendous success in the installation of gas and water lines, telecommunication cables and so on. Regardless of its enormous success in the other industries, the sewer industry has been slow to accept this technology. This chapter summarizes prior research which addresses the use of the HDD method for the installation of gravity sewer lines.

2.2 Advantages of Horizontal Directional Drilling

The main benefit of using HDD is that it is a form of trenchless technology which enables a variety of underground ducts and pipes to be installed with minimum disruption to the ground surface. HDD has several different advantages when compared to the traditional open-cut method of pipe installation. Some of which can be listed as follows:

a. The use of HDD enables reduction in the disruption of existing environment, traffic, or congested living and working areas.

b. It helps reduce the exposed working area, hence making the working site safer for both workers and the community.

c. It minimizes the cost of handling the soil required for bedding and backfilling of the trench in the open-cut method.

d. It helps eliminate the need for soil removal and minimizes damage to the pavement.

e. It helps trim down social costs which are associated with noise pollution, the disruption of the traffic, different aesthetic factors, and negative public perception.

HDD has several benefits not only in comparison to the open-cut method, but also when compared to other trenchless technologies which are being currently employed for the installation of on-grade gravity sewer pipes. Some of these advantages are as follows[5]:

a. It does not require vertical shafts during commencement of the drilling process from the ground surface.

b. It requires a relatively short setup time.

c. The single drive installation length exceeds that of any other non-man entry methods.

2.3 Problems Encountered During Directional Drilling

This section discusses the various problems identified by prior research on the use of HDD. In a study conducted by Allouche et al.[5], a survey was conducted with various different practicing professionals to determine the problems and difficulties which are likely to occur on any HDD project. This survey identified 8 different scenarios which included factors such as cave-ins, drill rod failure, etc. Based on the analysis conducted, it was found that the problem encountered most commonly on the job-site was that of loss of circulation in the flow of the drilling fluids. Whereas, the most uncommon problem encountered was the occurence of a void in the ground which would eventually lead to loss of circulation. Harrison et al.[2] also identified complications which could arise on the job-site. These factors included steering problems, drill rod failure, etc. Table 2.1 is a compilation of the results from both the research paper and the article. It summarizes the different scenarios which might be confronted when working on an HDD project and the different factors which might lead to their occurrence.

2.4 Slow Acceptance of HDD by the Sewer Industry

HDD has been widely accepted as a method of utility construction, because of its ability to make fast, and efficient installations even in situations where excavation seems to be an improbable option. However, the sewer industry has been slow and reluctant to accept HDD as a viable option for the installation of the gravity sewer lines. This section of the chapter discusses the reasons identified by various experts in the industry which limit acceptance of HDD on projects for installation of gravity sewer lines. It also focuses on the factors which need to be addressed in order to help the acceptance of this technology.

Table 2.1: Problems Encountered during Directional Drilling [1],[2]

No.	**Problems Encountered**	**Description**	
1	Steering problems	Soft clay or Loose Sand	Unable to offer significant shear resistance to steering tool
		Pedocretes or Rock	Drill head deflects off due to the harder material, leading to deviations
2	Tracking or locating systems	Disturbance & interferences due to the metallic or sources of magnetic fields on site	
3	Drill rod failure	Occurs due to excessive torque and pullback forces applied to a rig, mainly during reaming. It can also be due to operator error or poor maintenance	
4	Loss of circulation	Occurs in presence of a natural fracture in the formation or a leak to the surface due to the over-pressurizing fluids in the borehole	
5	Buried obstacles	Occurs due to unawareness about the presence of an underground utility. It can prove to be an expensive as well as a dangerous problem	
6	Cave-in of bore hole	Occurs when drilling through unconsolidated formations, locations where water table is fast moving or in cases of an excessively large bore hole very close to the surface	
7	Bending of rods	Occurs in cases when the maximum bending radius is exceeded	
8	Voids in the ground	Results in loss of circulation, in case of a small void, drill string can be pushed through it, otherwise needs to be realigned	
9	Inclement Weather	Presence of inclement weather and absence of proper gear with a sheltered operator shack causes delay in completion	

2.4.1 Reasons For Slow Acceptance

There are two main reasons for slow acceptance of HDD for the installation of sewer lines. They are 1. Inadequate awareness about the technology, and 2. A lack of belief that the equipment available can install pipes at critical grades. These viewpoints can be attributed to limited understanding and outdated information [7]. Based on the opinions of the people in the industry, the reasons why the sewer industry refrains from accepting HDD and exploiting its benefits are [8]:

a. The engineers who design the sewer systems do not want to change designs simply because HDD cannot consistently install tight grades below 0.5 percent.

b. The absence of a tight-fit, back reamed hole required to prevent pipe flotation has limited or more often precluded the use of HDD for a limited sector of the sewer industry.

c. The uncertainty that the main will be installed in its proper place prior to the full length of the pipe actually being put in place.

When using the traditional open cut method for the installation of the gravity sewer lines, the grades can be monitored at regular intervals by inspectors or contractors using survey techniques. Even with a trenchless technology like microtunneling, grades can be monitored during construction using a laser sight method.

2.4.2 Factors Needed To Be Addressed

The moderate and slow paced acceptance of HDD can be attributed to the limited knowledge about this technology and its benefits. Also there is very little evidence to substantiate the benefits of HDD to the sewer industry. Hence, there is a need to produce some evidence that HDD can install critical grades and if used appropriately, it can be very cost effective when compared to the traditional open-cut method and other trenchless methods. Two other factors that need to be addressed to make it possible for the sewer industry to adapt to this new method of installation are [8]:

a. The available technologies for the locating equipment need to be improved to allow more reliable indications in all areas of inter-city projects. It should be possible to record the actual location of the beacon housing for both line and grade without any airwave interferences and wire mess interferences on the job site. Another alternative could also be to develop a process which shall allow the accurate verification of the beacon housing at certain points during the entire installation procedure.

b. During the back reaming of the pipe being installed, there are chances of the deflection of the pipe and also pipe flotation, which affects the line and grade at which the pipe was installed. To be able to prevent this from happening it is necessary to install the pipe in a back reamed hole which is not very large as compared to the outside diameter of the pipe, while still preventing the pressure buildup in the hole.

2.5 Previous Implementation of HDD in the Sewer Industry

This section reviews four projects where HDD was used for installation of gravity sewer lines. Some of which were completed successfully while some were not.

2.5.1 Gravity Bore in City of Fort Worth, Texas

Planetary Utilities completed a gravity sewer bore for the City of Fort Worth, TX [9]. The bore was 837 feet in length which was completed in one shot and at the time was believed to be the longest gravity sewer bore completed using HDD. The grade on the project was 1.25%. This job had several challenges which included drilling at depths exceeding 30ft and through sandstone which progressively hardened with the increase in depth. The other challenge encountered was to install an 8inch ductile iron pipe which was to be housed in a 16 inch steel casing. In order to ensure the accuracy maintained while drilling the pilot hole, elevations were recorded after shooting every 10ft of the drill rod, also the crew custom built telescoping sleeves to align the reamers during the process of multiple backreaming. The project was completed in a period of 3 weeks.

2.5.2 Missouri Sewer Project

The Missouri Sewer Project[10], included installation of 1,440 linear feet of 16 inch diameter restrained joint PVC pipe as a part of the Mark Twain and Florissant Sanitary Relief Sewer Project. The pipes were to be installed at 0.86% slope and the depths varied from 14 to 26ft, with an average of about 20ft. The reasons for the selection of HDD as a method of installation for the gravity sewer line was based on the significant depths at which the pipe was required to be installed, unstable soil conditions, limited working space and the close proximity to the existing houses built in 1960's and 70's. The project involved two segments, the first including a 320 linear feet run in an alley and making a three-degree direction change to the new location of the manhole. The second segment of 400 linear feet continued along the remainder of the alley and under a five-lane concrete street.

This project in Missouri highlights the main advantages of using HDD in an urban area, where open-cut is not an option for installation of a gravity sewer line.

2.5.3 Sewer Mains and Laterals in Indiana

A sanitary sewer project in Carmel, Indiana[10] was performed using HDD. The purpose of this project was to extend the city's sewer system to some neighborhood residencies which were being served by septic tanks. The total linear feet of the gravity sewer pipe required to be put in place was 3,298, including an 8 inch PVC pipe, to be installed at average depths of eight feet, and 900 feet of a 6 inch PVC pipe. The sewer line was also required to maintain a grade of 0.4%, which was successfully accomplished by the crews by using a grade tracking system which could measure grades in 0.01% increments. The reason for the selection of HDD was the lack of space and also due to the requirement of the installation of a major section of the sewer line under concrete and asphalt pavements. This project was completed successfully saving the city $68,000 compared to the lowest open-cut bid received.

The success of this project indicates that it is possible to consider HDD as an option for installation of gravity sewer lines for grades below 1%.

2.5.4 Lewis Prison Bore

The Lewis Prison project[11] was located South of Buckeye, Arizona on State Highway 85. The bore consisted of two 12 inch water lines, an 8 inch effluent line and a 12 inch gravity sewer line, which were to cross the highway. The line was to be encased in a 0.25 inch steel casing sleeve and a 4 inch radial clearance was required to be maintained between the outside diameter of the utility line and the inside diameter of the sleeve. The contractor used a casing of larger diameter (24 inch) than required to provide some room for any alignment error. When the sewer line was attempted to be installed, the bore came in 10 inch high and 24 inch wide, the crew also pulled and grouted the 24 inch steel casing. In order to rectify the mistakes made by the contractor a horizontal-boring contractor had to be hired to attempt remediation of the bore. The initial schedule of the project included the completion of the job within 5 days, wherein the job took 14 days to be completed and also proved to be a financial disaster for the directional-boring contractor. The reason for the project failure was the presence of cobbles, which were a part of the highway embankment. The cobbles made it very difficult to control the drill head when boring the pilot hole.

This case study indicates the importance of understanding the soil conditions prevailing at the job-site. Due to the unawareness of the soil composition while selecting HDD as a method of installation, the project was a failure.

The four case studies reviewed indicate that it is of prime importance to be well aware of the various factors which determine whether the project will be a success or a failure. It is only after careful analysis that a decision should be made regarding the technology which should be adopted for the installation of the gravity sewer line. Based on the analysis of the case studies it is clear that when used with caution, HDD can be used to install gravity sewer lines with critical grades.

CHAPTER 3

Method Description

3.1 Introduction

This chapter discuses the tools and procedures involved in OnGrade^{TM} HDD for the pilot drilling and backreaming of the gravity sewer lines. This chapter first describes the process of calibrating the beacon present in the drill head with the tracker, the pilot drilling operation and the back reaming process by using the OnGrade^{TM} HDD method. This chapter will also describe a process of inspection which is used to ensure that the installed pipe was placed on the desired grade.

3.2 Process Description of OnGrade^{TM} HDD

The process of using OnGrade^{TM} HDD for the installation of gravity sewer lines can be described in three stages. The first stage involves the drilling of the pilot bore (Set-up of the drilling rig on the job-site can be seen in Figure 3.2(a)). The second stage involves the process of backreaming along with the pullback of the pipe material. The final stage involves the inspection of the installed pipe line. Figure 3.1 gives an overview of the installation process using the OnGrade^{TM} HDD technology. Since this chapter describes the methodology adopted by the OnGrade^{TM} HDD technology which has been developed by Charles Machine Works Inc, many sections of this chapter refer to an article 'Installation of Gravity Sewers Using Horizontal Directional Drilling'(HDD)[4] to best describe this method.

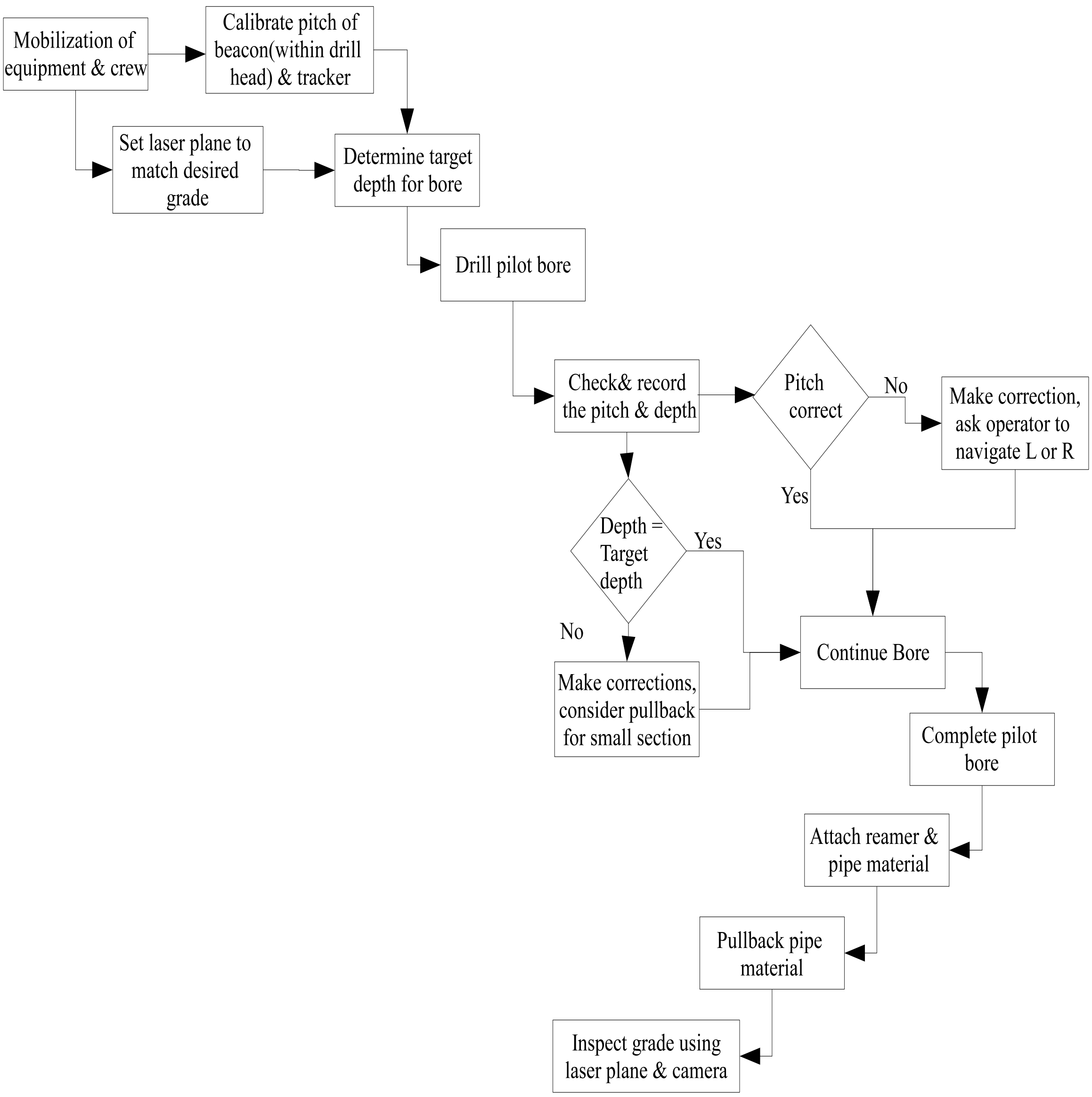
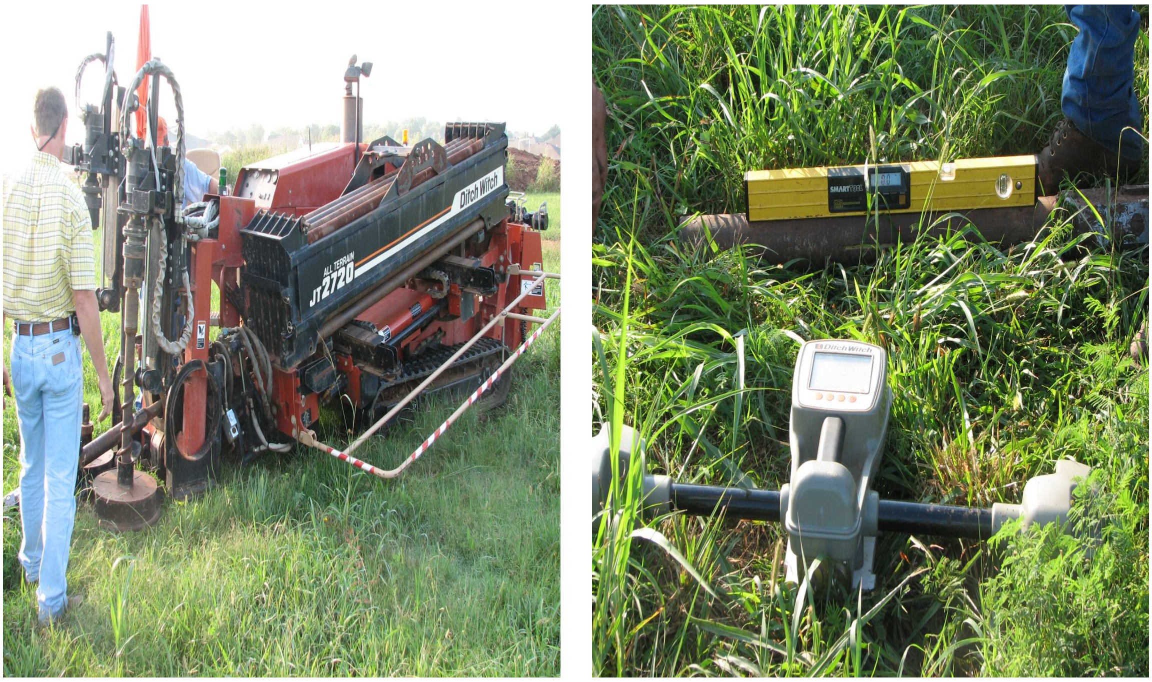


Figure 3.1: Flow Chart for OnGrade^{TM} HDD Installation Process

3.2.1 Stage I: Pilot Drilling

Drilling the pilot hole is a vitally important part in any HDD project. In the process of installation of a gravity sewer line, it is crucial to maintain the desired grade while drilling the pilot hole, because it determines the ultimate position of the installed pipe. There are a few factors which need to be considered before the drilling process is begun. One of the factors that needs to be considered is the ability to measure the inclination, or pitch, of the drill head in fine measurements to enable accurate reading of the grade of the pipe. To accomplish this accuracy, the OnGrade^{TM} HDD technology uses the grade capable beacons (sondes). These are the transmitters which are placed in the drill head at the leading end of the directionally drilled bore. Prior to conducting a bore using the OnGrade^{TM} HDD, the pitch and depth readings of the beacon, or sonde, should be calibrated following the manufacturers instructions to remove any pitch errors present. The Figure 3.2(b) shows the process of the calibration of the beacon.



(a) (b)

Figure 3.2: (a) Set-up of the Drilling Equipment (b) Calibration of the beacon

The drilling operator guides the drill head down to the correct depth and starting pitch at the beginning excavation for the sewer installation(see Figure 3.4). Next, a laser plane with a dial in grade capability is established at or near the start of the bore as shown in Figure 3.3(a). The grade of the laser plane is set to match the desired grade for the sewer installation. This system also includes a special ”grade pole” to which the 8500 TK tracker system is mounted, which is in communication with the 8500 TK. The 8500TK is an advanced electronic guidance system which is

(a) (b)

Figure 3.3: (a) Setting up of Laser Plane (b) Grade Pole with Tracker

manufactured by Ditch Witch. The grade pole includes two parallel fiberglass tubes, one of which sets on the ground, and the other one may translate up and down relative to the first as seen in Figure 3.3(b). Electronics within the grade pole measures the relative position of the tubes. Laser receiving sensors mounted to the movable tube allow the pole to measure the height of the laser plane above the tracker unit. At or near the start of the bore, a depth is taken of the total distance from the laser plane to the center of the drill head. The 8500 TK unit calculates the depth from itself to the drill head, and the grade pole provides the elevation measurement from the laser plane to the tracker. These two distance measurements are added by the tracker and transmitted by radio link to the drill operator. This depth serves as the target depth for the entire bore. If the drill head remains on the desired grade, the total depth between the laser plane and the drill head will remain constant throughout the length of the bore. The drill operator will drill at reasonably short intervals, typically from 3-5 ft while monitoring the pitch of the drill head as he or she drill. At the end of each interval, a measurement is again taken of the depth from the laser to the drill head and the operator may make adjustments to the pitch at which they are drilling accordingly. This system provides a continuous grade reference along the bore path. The depth of the drill head may be checked relative to a standard at any point along the bore. The computations for the drill operator are very simple, if the depth from the laser plane to the drill head is greater than the target depth, the bore is below the desired line. If the depth from the laser plane to the drill head is smaller than the target depth, the bore is shallow.

One point of weakness of this system is that the depth estimate at any point is only as good as the accuracy of the tracking system. The stated accuracy for the 8500 TK system is +/- 3% of the measured depth for depths down to 30'. Additionally the system requires a line of sight along the bore path (although it is possible to reset the laser plane at various points along the path to accommodate obstacles in the path).

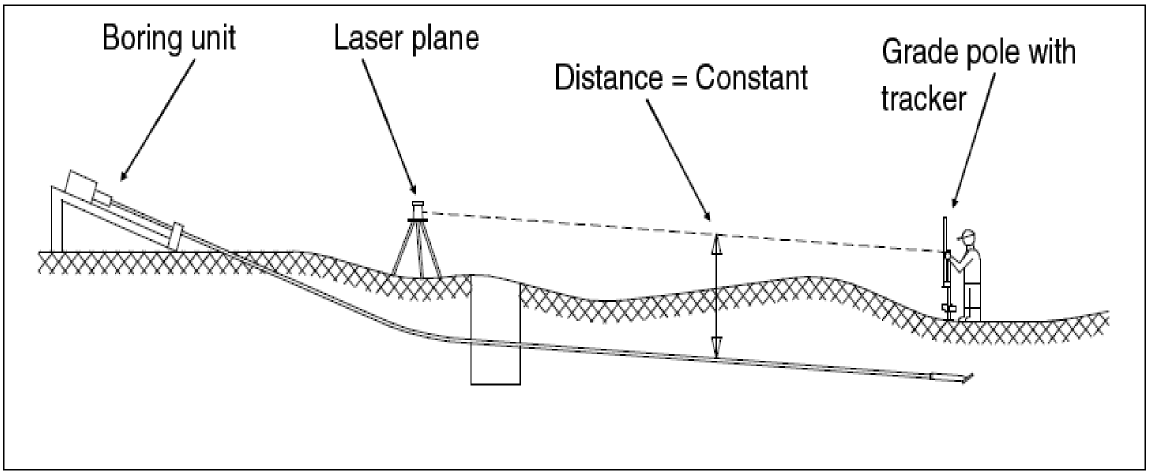


Figure 3.4: CMW Grade Drilling Method [4]

3.2.2 Stage II: Backreaming and Pullback of Pipe Material

For the process of backreaming and pullback operations, a single reaming pass is used to open the hole to the desired diameter. The Figure 3.5(a) shows the attached reamer and Figure 3.5(b) shows the pipe to be installed, attached to the reamer for the pullback process. The backreaming process utilizes an over-cut of the borehole comparable to those used for non-gravity flow installations. By over-cutting the borehole and allowing the slurry to flow over the annulus of the installed pipe, slight bobbles in pitch that occur when drilling may be taken out. The backreamed slurry is allowed to flow past the installed pipe, keeping the interior of the pipe unfouled, and use of jointed pipe is possible. However, the over-sized hole provides potential for the installed pipe to float slightly within the borehole during installation and may reduce the overall precision of the installed pipe placement.

(a) (b)

Figure 3.5: (a) Reamer used for Backreaming Process (b) Pullback of Product Pipe

3.2.3 Section III: Inspection

Inspection is the last and final stage in the process of installation of the product pipe. Since the maintenance of the grade is an important factor during the installation of a gravity sewer line, it is necessary to inspect the line and ensure that there are no dips or rises which may affect the use of the installed product pipe. In order to inspect for the presence of any major dips or rises, the following methods are typically used:

(a) (b)

Figure 3.6: (a) Water Test being Conducted (b) Camera and Beacon being used for the Inspection Process

a. A water test can be conducted (See Figure 3.6(a)). This test would include pouring a known quantity of water into the installed pipe and collecting the water at the other end and checking the amount. If a large quantity of water is lost during the transition in the pipe it would indicate the presence of dips and rises in the installed pipe.

b. Another method would involve passing a camera through the installed pipe after the above stated water test has been conducted. Doing so will allow the inspector to see and locate the points where the water is located and thus identify the dips and rises in the pipe.

c. Along with the above stated methods, it is also an option to pass the beacon through the installed pipe while passing the camera through it(See Figure 3.6(b)). The 8500 TK Tracker system collects the pitch readings at regular intervals of around 5 to 10 feet. These readings can then be compared using graphs with the desired pitch readings to see whether the installed pipe line is on the desired grade and level.

CHAPTER 4

Survey Analysis

4.1 Introduction

A survey questionnaire was sent out to contractors throughout the US to obtain their experiences with using the HDD method for the installation of gravity sewer lines. The purpose of this survey was to obtain information regarding the advantages, limitations, and problems faced when using HDD for sewer construction. The survey was sent out to contractors with prior experience with on-grade HDD with the help of the National Utility Contractors Association (NUCA) and several contractors which had been identified during the literature review.

The development of the survey was based on the findings of the literature review and the inputs provided by the professionals in the industry who had worked with both HDD and open-cut method. The questionnaire consisted of four different types of questions. The first set of questions was intended to collect information about the contractor responding to the survey and his/her experience with the use of HDD and open-cut method for installing gravity sewer lines. The second set of questions was directed towards identifying their views on the advantages and limitations of using HDD method in comparison with the traditional open-cut method. The third set of questions focused on determining the extent of the effects of factors such as pipe material, soil type and so on, on the line and grade maintenance when using the HDD method. The fourth set of questions was intended to obtain additional comments and recommendations which the contractors may have to share regarding the use of HDD.

4.2 Survey Analysis

In total 12 responses were received. Based on the responses received to the questions regarding prior experience with the open-cut method and HDD for installing gravity sewer lines, it was noted that every contractor had used the traditional open-cut method. But only 83.33% of the contractors had prior experience with using HDD as a method of installation. 66.67% of the contractors agreed that the use of HDD had several advantages over the use of open-cut method for sewer construction.

The contractors were asked to rate the advantages of using HDD as a method of installation in comparison to the use of the open-cut method. Figure 4.1 shows a graphical representation of the responses received in terms of the advantages associated with the use of HDD. All of the contractors unanimously agreed that the use of HDD reduces the restoration costs associated with a project. More than 80% of

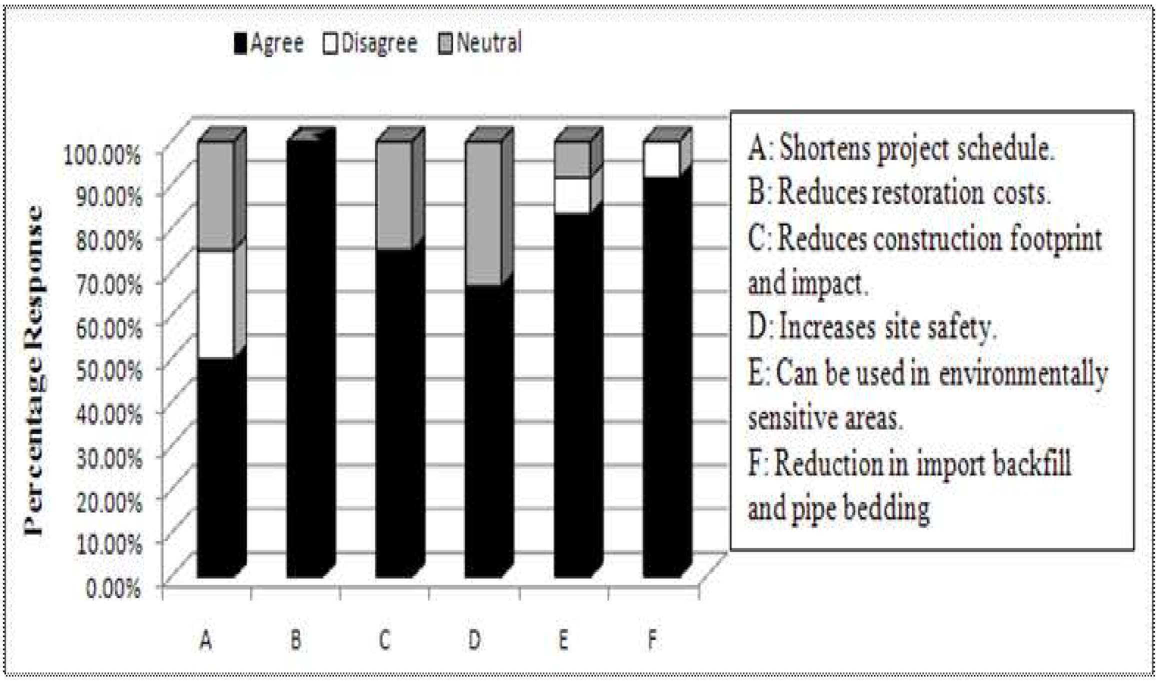


Figure 4.1: Advantages of using HDD

the contractors also agreed that the use of HDD would drastically reduce the cost of importing the backfill and pipe bedding material which would be required with the use of the open-cut method. They also reported that it was possible to use HDD as a method of installation in environmentally sensitive areas. 50% of the respondents either disagreed or had a neutral response about the fact that the use of HDD could help shorten the project duration.

The contractors were also asked to rate the limitations associated with the use of HDD when compared to open-cut method. More than 75% of the respondents agreed that maintaining the line and grade of the pipe being installed and the number of connections required are the two major limitations associated with the use of this method. The other limitating factors identified in the survey can be seen in Figure 4.2.

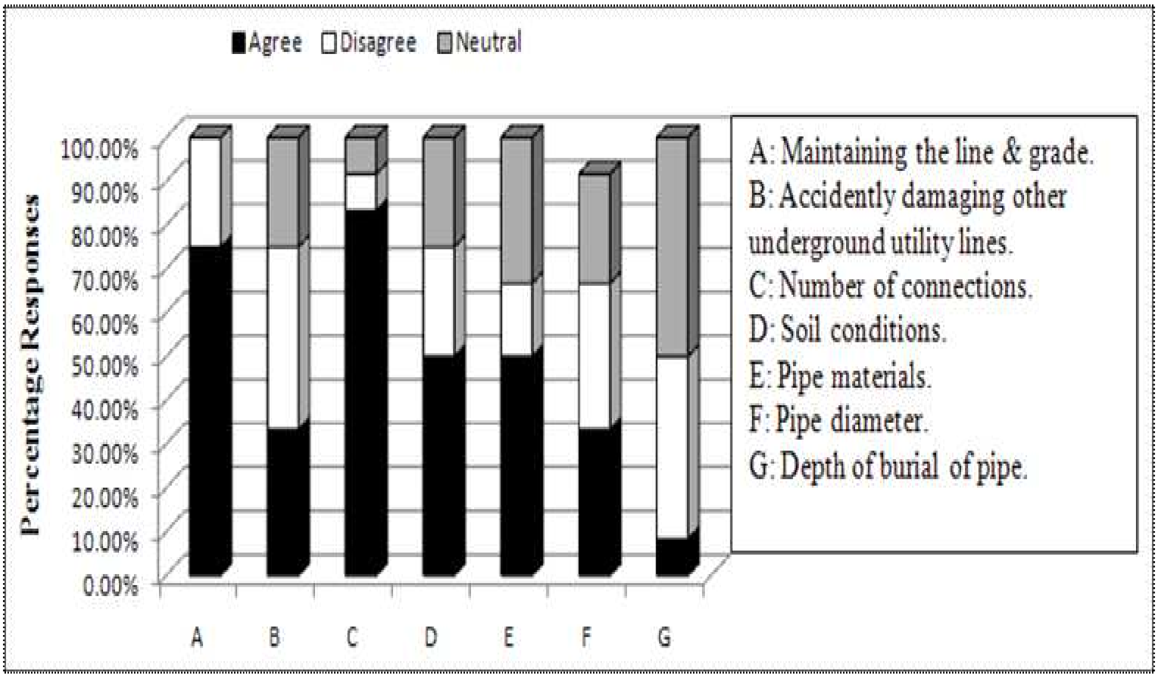


Figure 4.2: Limitations associated with the use of HDD

The questions in the next section focused on understanding the perceptions of the contractors on issues such as the different pipe materials and the type of soils which are most suitable for HDD. It also focused on identifying the perceptions regarding the factors which affect the maintenance of the line and grade when using HDD.

The responses of the contractors in terms of the pipe materials best suited when using HDD were very widespread. More than 50% of the respondents agreed that Ductile Iron and Polymer Concrete pipes are not suitable for use with HDD. Whereas, Fusible Polyvinyl Chloride and High Density Polyethlyene pipes are the most suitable pipe materials. Figure 4.3 shows the percentage reponses for the different type of pipe materials that can be used for HDD installations.

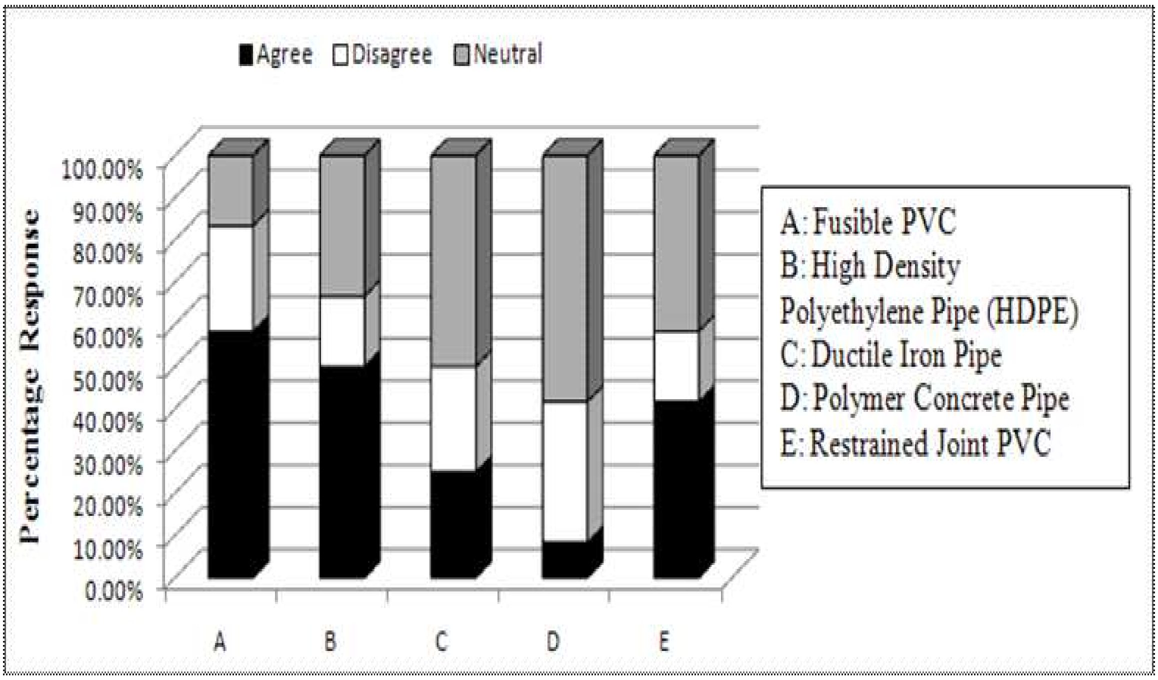


Figure 4.3: Choice of pipe materials for use with HDD

The next question dealt with the different factors which affect the maintenance of the line and grade of the drilling rig when using HDD. Figure 4.4 shows the survey results. 83.33% of the respondents reported that the difficulties encountered in maintaining the line and grade while using HDD could be attributed to the presence of unexpected soil conditions. Two other factors which 75% of the respondents thought to be the major contributors are the absence of realiable tracking equipment and the in-ability to maintain the grades during the pullback proocess.

The contractors were asked to rate the soils according to their suitability for the

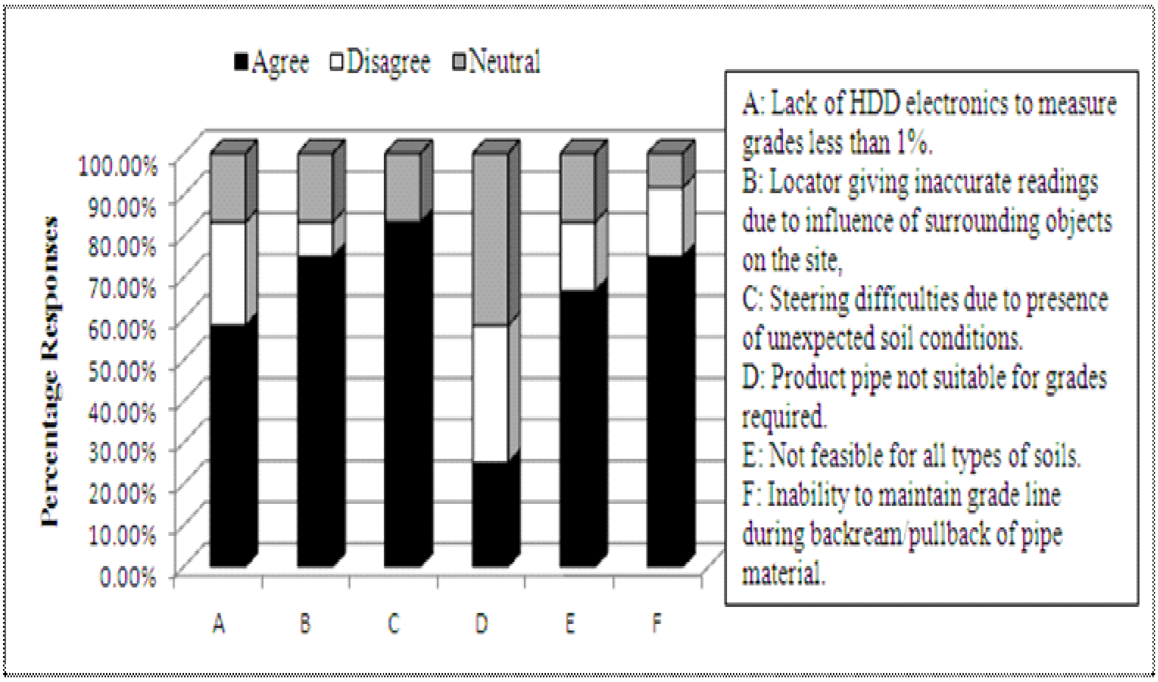


Figure 4.4: Factors affecting the line and grade maintenance

use of HDD. Their responses have been summarized in Figure 4.5. The majority of

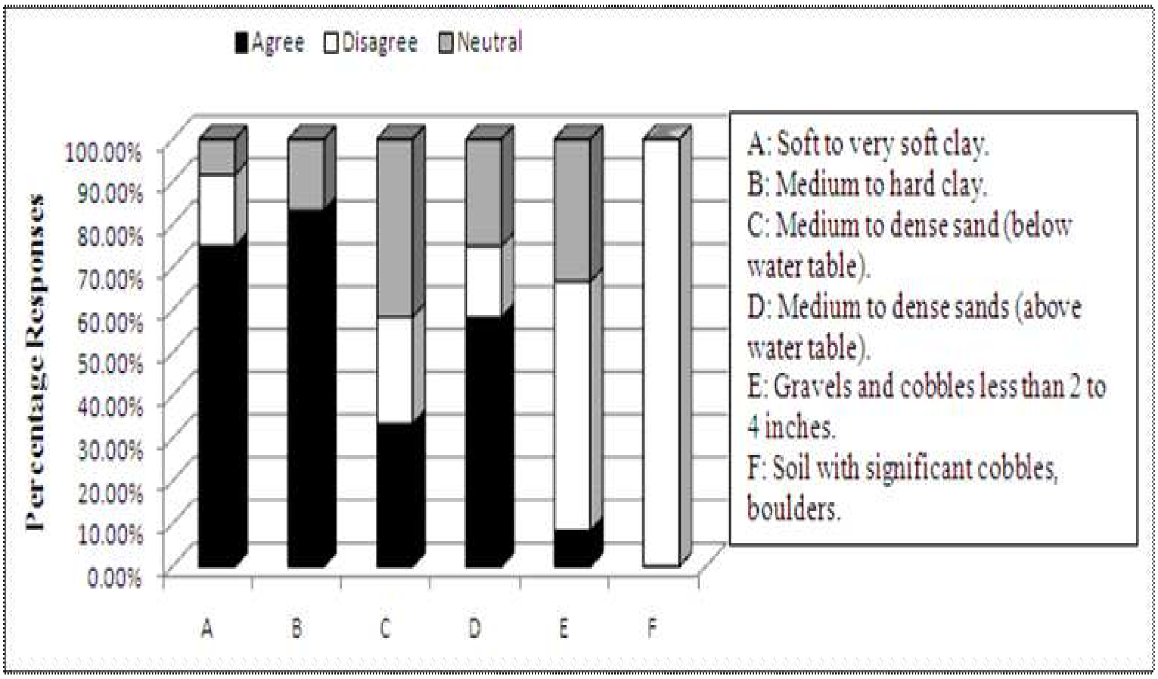


Figure 4.5: Effect of the types of soil on use of HDD

the respondents identified medium to hard clay soils as the ideal soil material when using HDD. Whereas, soil with cobbles and boulders provided the most unfavorable soil conditions for the use of HDD.

4.3 Summary

The responses of this survey questionnaire substantiated the need for this research. Despite the awareness of this application of this HDD method, not all respondents were in favor of using HDD to install gravity sewer lines. The inputs provided by the contractors who responded to this survey, have been used further in this research as one of the sources to determine the type of data to be collected during the field tests. These inputs have also been used to formulate the decision support system.

CHAPTER 5

Case Studies

5.1 Introduction

This chapter includes detailed information about the field tests conducted to collect real data for the analysis of the cost and time efficiency of using OnGrade^{TM} HDD for the installation of gravity sewer lines when compared to the traditional open-cut method.

Two field tests were conducted within the state of Oklahoma using the OnGrade^{TM} HDD method. The following factors were considered in the field test; site conditions, crew size, duration of the project, cost incurred for execution of the project, rate of installation, the accuracy of the installation, the advantages and disadvantages associated with the use of the OnGrade^{TM} HDD method.

Based on the data collected during the field tests, the direct and indirect costs associated with the use of the OnGrade^{TM} HDD method, cost per linear foot of installation, and the speed of installation were calculated. The problems encountered and the limitations of the On-Grade HDD method observed on the job-site helped identify the boundary conditions for the application of this method.

This chapter is divided into two main sections. The first section describes the techniques and methods used to conduct an cost analysis on the data collected. It also discusses the different factors taken into consideration when calculating the direct costs and indirect costs associated with the use of the OnGrade^{TM} HDD method and the traditional open-cut method. For the purpose of a comparative study, the cost analysis for the implementation and the use of OnGrade^{TM} HDD method has been based on the data collected during the field tests. Whereas, the cost analysis of the implementation of the open-cut method is based on the plans, drawings and the information provided by the project owner. The second section of this chapter includes detailed information about the projects where the field tests were conducted.

5.2 Methodology Adopted for Cost Analysis

This section describes the methods adopted and the factors affecting the calculation of the the direct and social costs when using each method.

5.2.1 Direct Cost Analysis

The direct costs associated with a project are defined as the costs which are directly linked to the physical construction of the project. The main factors associated with the calculation of the direct costs of the open-cut method as well as the OnGrade^{TM} HDD method can be seen in Table 5.1. This section discusses the affect of each of the cost factors on the costs associated with the method adopted to install a gravity sewer line.

The factors which are stated as Not Applicable towards a particular method of installation are the ones which do not affect the cost associated with that method. Whereas, the cost factors which are mentioned as either Considerable or Inconsiderable affect the costs associated with the corresponding method of installation either substantially or insignificantly. And finally the cost factors whose affect is mentioned as varies are the ones whose affect depends on and changes with the project conditions. For instance, the mobilization and demobilization costs associated with a project varies depending on the location and the site conditions prevailing at the job-site irrespective of the method of installation adopted. Also, the equipment required on the job-site changes in accordance with the project conditions, hence affecting the costs associated with the same. The costs of excavation associated with the open-cut

Table 5.1: Factors Affecting Direct Costs for Gravity Sewer Construction

Cost Factors	**Open-Cut Method**	**OnGrade^{TM} HDD Method**
Mobilization & Demobilization	Varies	Varies
Detour of Roads	Considerable	Not Applicable
Shoring of trench	Considerable	Inconsiderable
Removal of spoil	Considerable	Considerable
Excavation of trenches	Considerable	Inconsiderable
De-watering of trench	Considerable	Varies
Backfilling and compaction	Considerable	Not Applicable
Reinstatement of surfaces	Considerable	Inconsiderable
Construction equipment costs	Varies	Varies
Labor costs	Considerable	Inconsiderable
Material costs	Considerable	Considerable

method are considerable since it involves trenching the entire length of the sewer line. This also increases the costs of shoring of the trenches and reinstatement of the surfaces. Thus, it is concluded that these factors considerably affect the costs of a project. Whereas, when using OnGrade^{TM} HDD method for the installation of the sewer line, excavation is limited to sections which require installation of a manhole or connections for a lateral. Thus, the cost of shoring the trenches and reinstatement of the surfaces is also reduced proportionately, reducing the costs associated with the same. Factors like de-watering of a trench or backfilling and compaction are associated with only the open-cut method of installation and hence do not have any impact on the costs when the OnGrade^{TM} HDD method is used. The backfill and compacting material required for any open-cut project has a significant impact on the cost of a project. Whereas, when using the OnGrade^{TM} HDD method the cost associated with the pipe material used on the project contributes significantly to the costs. Thus, the material costs associated with both the methods of installation are concluded as Considerable. Hence it is very important to carefully analyze the factors associated with both the installation methods. This helps achieve better understanding of the economic suitability of each method and also the economic benefits of using one method over the other.

5.2.2 Social Cost Analysis

Social costs are the costs incurred due to factors which are not linked directly to the physical construction of the project. These costs include the social costs associated with the project. The various factors which affect the social costs can be identified as road damage, noise and vibration, damage to adjacent utilities, damage to adjacent structures, air pollution, cost of vehicular or traffic disruption, pedestrian safety, damage to detour roads, citizen complaints, environmental impacts, and so on[12]. One of the most important factors is the cost of vehicular and traffic disruption. The following are the major elements considered in this research for estimating the cost incurred due to vehicular and traffic disruption[12]:

- Cost of fuel
- Cost of travel time

In a scenario that a gravity sewer line is to be installed crossing a street using the traditional open-cut method, it would require a trenching section of the street. This in turn requires detouring the traffic through a different route. Thus, the duration of the project also affects the social costs associated with a project. For the purpose of this research two main factors including the cost of fuel and the cost of travel time have been considered to analyze the social costs. The selection of these two factors has been based on the fact that these are the major contributors to the social costs associated with a project.

The cost of fuel is directly proportional to the distance in miles of the detour route. The additional miles traveled help determine the additional gallons of fuel required. The cost of fuel for detour roads is calculated using Equation 5.1

$$\frac{\text{Detour roads fuel cost}}{\text{vehicles}} = \frac{\text{avg gal.}}{\text{mile}} * \text{ avg additional miles } * \frac{\text{avg fuel cost}}{\text{gal.}} \tag{5.1}$$

The cost of travel time is the product of the additional time spent traveling (measured in minutes or hours) multiplied by the unit costs (measured as dollar per hour). The cost of travel time can be calculated using the equation given below:

$$\begin{aligned} \text{Cost}_{\,traveltime} &= \text{AW} * \text{ADT} * \text{AT} \qquad (5.2) \\ \text{Where:} & \\ \text{AW} &= \text{Average Wage} \\ \text{ADT} &= \text{Average Daily Traffic} \\ \text{AT} &= \text{Time required to travel additional miles} \end{aligned}$$

Based on the method described above, a detailed cost analysis was conducted on the data collected during the field tests. The next section of the chapter describes the project requirements, site conditions and the process of execution of each field test conducted. It also includes a comparative cost analysis of the open-cut method and the OnGrade^{TM} HDD method for installing a gravity sewer line in different scenarios (project site conditions).

5.3 Field Test I: Arbor Village Project, Stillwater, Oklahoma

The Arbor Village Project in Stillwater, Oklahoma is a land development project that consists of 37 lots which include 4 commercial lots and 33 single family lots on 20 acres located at the southwest corner of W. 19th Avenue and S. Western road. A section (manhole to manhole) of the gravity sewer line in this project was installed successfully with the use of OnGrade^{TM} HDD method. The details of the job conditions are given below:

a. Total length of gravity sewer pipe required to be installed: 265.7 linear feet

b. Pipe material:HDPE

c. Pipe diameter: 8 inches

d. Soil type: Clay

e. Grade: 0.5 %

The layout of the project job-site can be seen in Figure 5.1. The installation of the sewer line started at a manhole location on the south (point 1) and crossed the 19th street and ended at a manhole location on the north (point 2). The depth of the pipe required at the starting point was 7.91 ft and the depth at the ending point was required to be 9.13 ft. Thus the elevation difference between the two points is 1.22 ft over a length of 265.7 ft (0.5%).

Based on the project specifications, a steel casing was required to encase a partial section of the sewer pipe which runs below the 19th Street and the sidewalk. A steel casing of 12 inch diameter and length of 115.7 ft was also installed with the HDD equipment as a part of this project. During the execution of the project it was also observed that the water table present on the job-site was high.

The procedure of installing the pipe using the OnGrade^{TM} HDD method was similar to the procedure and techniques described in Chapter 4. However, as the project involved the installation of a steel casing, it required some additional work. A pit was made just on the south end of the 19th street to have working space to attach and detach the reamer for installing steel casing. Following the drilling of the

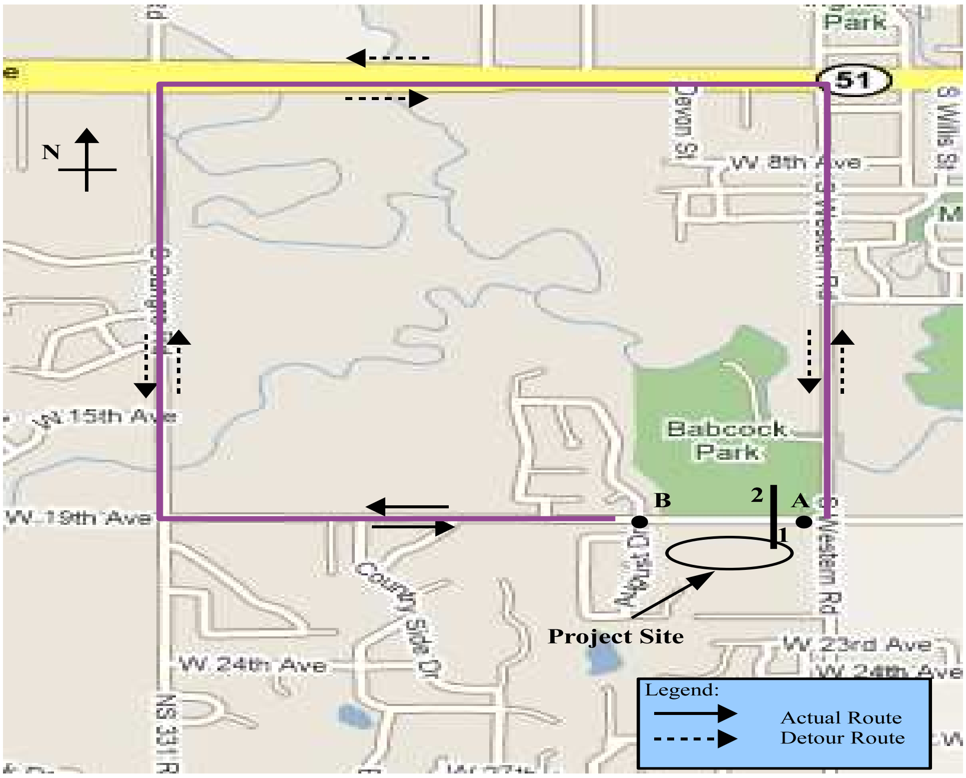


Figure 5.1: Sketch of Project Job-Site

pilot hole to its final length, a back reaming operation was done under 19th Street to accommodate the insertion of the steel casing. On reaching the pit on the south side of the street, the reamer was detached and the drill pipe was passed through this section and connected using a casing pulling head and the casing was pulled into place. In order to attach and pull the HDPE product pipe, the drill pipe was pushed through the casing and the pipe material was attached and pulled back through the casing. Once the end of the product pipe was through the steel casing, the reamer was attached again to the drill pipe and the HDPE pipe was attached to it. The remaining section was then pulled back using the traditional HDD method. It took three days to install and inspect the 265.7 ft of gravity sewer line using the OnGrade^{TM} HDD method.

Since the Arbor Village Project is still an on-going project, an official inspection by city inspectors has not been performed. However, as a part of the case study, an inspection was conducted by checking the installed depth using a beacon, tracker and running a camera through the inside of the installed pipe to check and record the presence of any dips or rises. Figure 5.2 illustrates the internal inspection results.

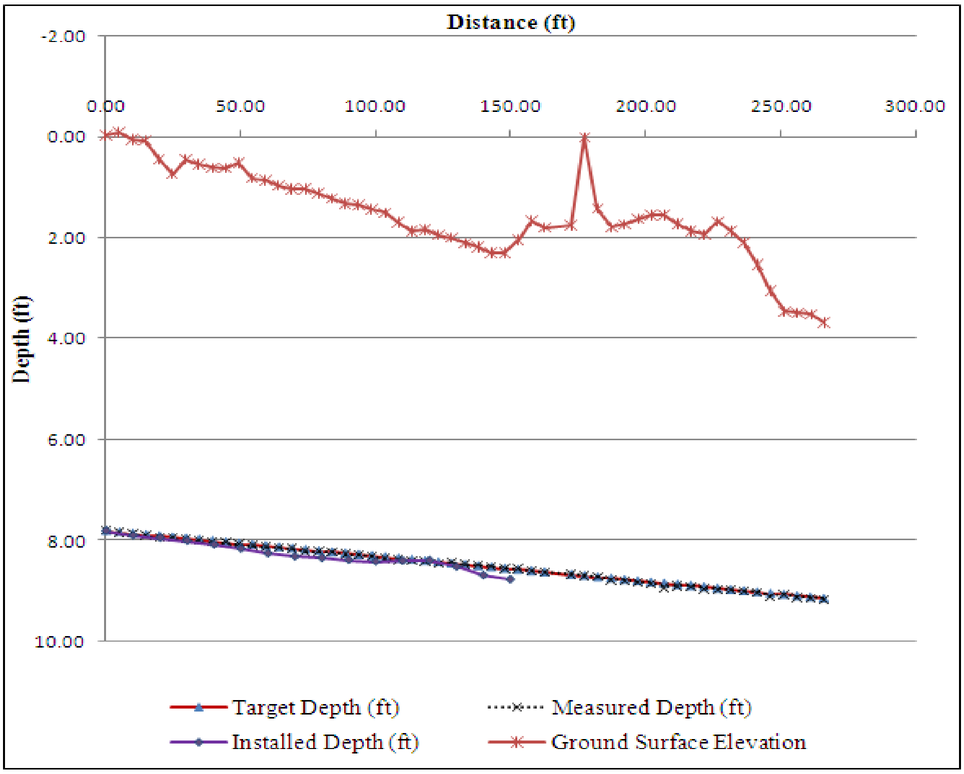


Figure 5.2: Bore plot showing the desired and final grade(Arbor Village Project)

Figure 5.2 is a profile view of the job site which provides the ground elevation of the job-site, target depth of the sewer line, measured depth of pilot bore drill, and installed depth of the sewer line. The measured depth is the depth of the drill head recorded by the tracker based on the signal sent by the beacon during the pilot bore drilling process, whereas the installed depth is the depth by pitch recorded by the beacon during the inspection process. Since the installed depth of the pipe was recorded using the beacon and tracker, it was not possible to record the readings of the pipe section encased within the steel casing. This was because the steel casing obstructed the signals from the beacon.

5.3.1 Cost Analysis

In order to compare the costs associated with the use of the OnGrade^{TM} HDD method with the traditional open-cut method, a detailed cost analysis was conducted. Since the installation of the gravity sewer line in this case study was completed by using the OnGrade^{TM} HDD method, the OnGrade^{TM} HDD costs were determined by using actual data. However, the costs associated with the use of the open-cut method were calculated mainly with R.S. Means Cost Guide based on the quantities from the plans and drawings provided by the project owner. In this section, two different cost analysis scenarios are discussed. They are:

- Scenario A: Project site conditions exactly the same as the case study.
- Scenario B: Assumed that there is no 19th Street, hence no installation of the steel casing. The remaining site conditions are the same as the case study.

The following assumptions were made for calculating the costs using the two methods for the case study:

- The unit cost calculations for the OnGrade^{TM} HDD method are based on the ownership costs of the equipment like the drilling rig, tracking electronics, truck/trailer and the vacuum system.
- The calculation of the costs associated with the OnGrade^{TM} HDD method is based on actual equipment and labor hours measured on site.
- When calculating the excavation costs associated with the open-cut method of installation, a sloping trench excavation has been considered. This assumption has been based on the Occupational Safety and Health Administration (OSHA) regulations (Standard Number 1926.652(a) and (b)) which requires providing sloped sides for a depth greater than 5ft.

- The costs for installing the steel casing using the OnGrade^{TM} HDD have been included and the costs for the open-cut method were estimated based on time and resources required to do so.

- The material costs for sewer pipe and steel casing are not included.

- The cost calculations of the open-cut method are based on the quantity take-off in accordance with the plans and drawings provided by the project owner.

Scenario A

Scenario A is based on the actual site conditions present at the job-site. Table 5.2 shows the cost calculations and the cost per linear foot, when the open-cut method is used. Since the open cut method has to disrupt the traffic on the 19th street, the costs of the removal and reinstatement of the asphalt pavement are included.

The traffic disruption expected and the need to use detour roads during the construction work causes the social costs to be included in the cost estimate. The main factors that affect the cost associated with vehicular and traffic disruption are the duration of the project and the cost of fuel. The calculation of the cost of traffic disruption has been based on the cost of fuel consumed for the additional miles required to be traveled (Bhavani et al. 2003). The Average Daily Traffic (ADT) recorded on this street was 7,978 vehicles in 24 hour duration in March 2008 (recorded by the City of Stillwater). For calculation purposes, it was assumed that out of the 7,978 vehicles there were 2% buses, 50% trucks/pick up vans and 48% sedans. This assumtion has been based on the information collected during discussions with the city officials regarding the ADT encountered on the 19th Avenue. The fuel consumption was estimated at 14.3 miles per gallon for buses, 16 miles per gallon for pick-up/trucks and 25 miles per gallon for sedan cars (USEPA 2008) and the cost of fuel is estimated at $1.71 per gallon (Oklahoma Gas Prices 2008) as of January 17th 2009. Table 5.3

Table 5.2: Direct Cost Calculation for Open-Cut Method (Scenario A)

Work Item	Unit	Unit Cost	Quantity	Total Cost ($)
Mobilization & Demobilization	Ea	168.50	2.00	337.00
Pick-up truck 4-wheel drive	Ea	190.00	1.00	190.00
Excavation	C.Y	4.45	1124.83	5005.49
Bedding Material	C.Y	33.81	76.53	2587.48
Compacting Backfill	C.Y	2.22	877.11	1947.18
Dewatering	Day	115.50	3.50	404.25
Pavement Removal	S.Y	4.96	53.33	264.52
Asphaltic Concrete Pavement Reinstatement	S.F	1.79	480.00	859.20
Sidewalk Removal	L.F	5.91	12.00	70.92
Concrete Sidewalk Reinstatement	S.F	2.75	96.00	264.00
Total Cost				11930.04
Total Length of Installation	L.F		265.70	
Cost per linear foot				**44.90**

summarizes the per day fuel costs incurred.

Assuming that each vehicle is occupied by an average of 1.22 persons [13], 9733 people per day (7,978 vehicles * 1.22 persons) would be affected by the detour. The installation of the gravity sewer line using the open-cut method would put the road out of service for 2 days. Hence, 19,466 (7,978 vehicles * 1.22 persons * 2 days) people are affected by the detour over the 2 day period of the construction. Figure 5.1 shows the detour route which would be adopted in a scenario of the closure of the 19th street. The additional distance required to be traveled from point A to B using the detour route was 3.4 miles. Also, the average speed limit on the route was known

Table 5.3: Indirect Costs Associated with the Open-Cut Method

Category	Average Daily Traffic	Average mileage per gallon	Fuel price	Fuel cost for actual miles	Additional fuel cost for detour miles
Buses	160	14.3	2.09	\$7.02	\$120.06
Pick-up/Trucks	3,989	16	1.71	\$127.89	\$1,577.4
Sedan	3,829	25	1.71	\$78.57	\$969.04
Total Costs				\$213.48	\$2,666.5

to be 35 miles/hour. hence, this would add an additional ten minutes to the travel time. 10 minutes for 19,466 people adds up to approximately 3244 man-hours over a period of two days. The average persons wage rate can be assumed to be \$15.00 per hour. Thus, the social cost due to lost time for a 2 day detour would be \$48,660.

Table 5.4 given below explains the costs associated with the implementation of OnGrade^{TM} HDD for the installation of the 265.7 ft of gravity sewer line using actual data collected from the job site.

A summary of the costs associated with this scenario of the Arbor Village Project can be seen in Figure 5.3. Figure 5.3(a) shows that the use of the OnGrade^{TM} HDD method on the Arbor Village Project caused a reduction in the direct costs by \$6,566.37. Also, the use of OnGrade^{TM} HDD on this project scenario deferred the social costs of \$53,990 over a period of two days. Figure 5.3(b) shows the per linear foot costs associated with the use of both the OnGrade^{TM} HDD method and the open-cut method.

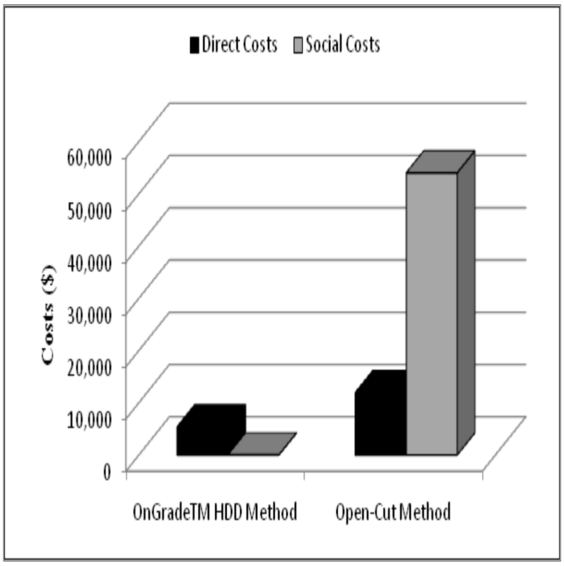
Scenario B

Scenario B assumes that there is no roadway (19th St.) above the sewer line, so there is no need to install steel casing. This assumption eliminates the costs associated with

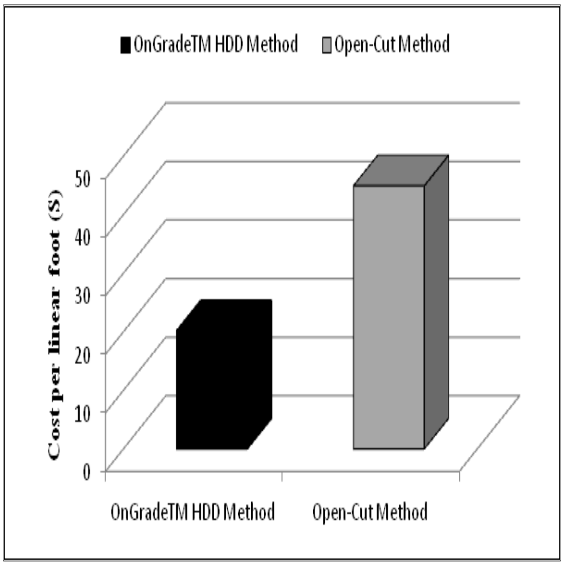
Table 5.4: Direct Cost Calculations for OnGrade^{TM} HDD Method (Scenario A)

Work Items	Unit	Quantity	Unit Cost	Total Cost ($)
Drilling Unit	Day	3	$199.21	597.63
Drill pipe and Tooling	Day	3	111.11	333.33
Tracking Electronics	Day	3	75	225
Truck/Trailer (includes fluid mixing system)	Day	3.00	132.68	398.04
Drilling Fluid Additives	Project			200
Vacuum System	Day	3	46.64	139.92
Maintenance	Day	3	94.63	283.89
Drill Operator	Day	3	200	600
Locator	Day	3	180	540
Helper	Day	3	160	480
Insurance	Day	3	135	405
Fuel	Day	3	150	450
Batteries	Day	3	20	60
Mobilization Demobilization	Project			468.50
Excavation	Project			182.36
Total Cost				5,363.67
Total Length of Installation	L.F.		265.7	
Cost Per Linear Foot				20.19

the removal and reinstatement of the asphalt pavement and the sidewalks and also the social costs associated with the project. This scenario analysis was performed to compare the costs of the two methods in normal site conditions without involving



(a)



(b)

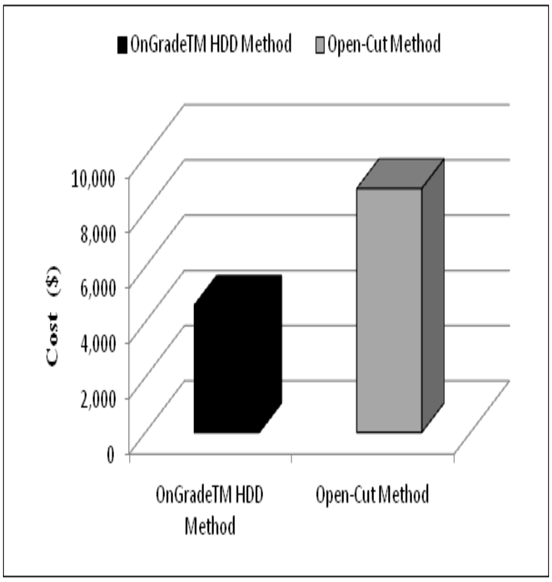
Figure 5.3: (a) Cost Comparison of Direct and Social Costs of Scenario A (b) Cost Comparison of the Direct Costs(Per Linear Foot)

roadway disruptions. Table 5.5 shows the cost calculations and the cost per linear foot when the open-cut method is used. When the OnGrade^{TM} HDD is used for this scenario, the required time to complete the job will be reduced from the time calculated for Scenario A since there is no need to install the steel casing. It is estimated that approximately 3 hours will be saved, which is about 14.28% of the total time required for scenario A. The total cost when using the OnGrade^{TM} HDD for Scenario B was calculated accordingly. This cost is estimated to be $4,597.73 and the cost per linear foot is $17.30/lf.

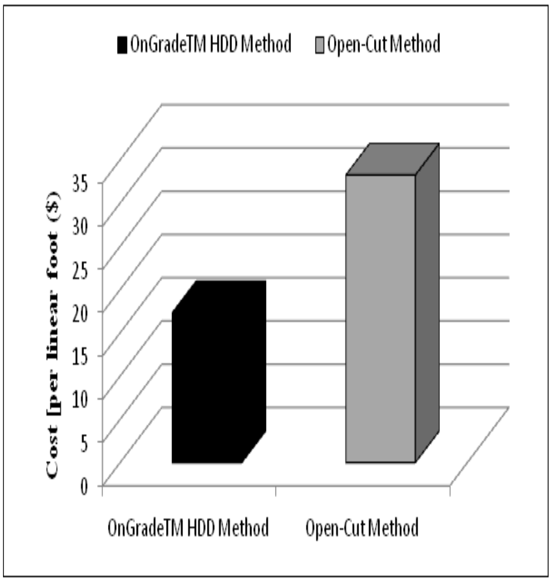
A summary of the costs associated with this scenario of the Arbor Village Project can be seen in Figure 5.4. Figure 5.4(a) shows that the use of the OnGrade^{TM} HDD method on the Arbor Village Project caused a reduction in the total costs by $4228.97. Also, Figure 5.4(b) shows the per linear foot costs associated with the use of both the OnGrade^{TM} HDD method and the open-cut method.

Table 5.5: Direct Cost Calculations for Open-Cut Method (Scenario B)

Work Item	Unit	Unit Cost	Quantity	Total Cost ($)
Mobilization & Demobilization	Ea	168.50	2.00	337.00
Pick-up truck 4-wheel drive	Ea	190.00	1.00	190.00
Excavation	C.Y	4.45	932.62	4,150.16
Bedding Material	C.Y	33.81	60.74	2,053.62
Compacting Backfill	C.Y	2.22	837.69	1,637.67
Dewatering	Day	115.50	3.50	404.25
Total Cost				8,826.70
Total Length of Installation	L.F			265.70
Cost per linear foot				**33.22**



(a)



(b)

Figure 5.4: (a) Cost Comparison of Direct and Social Costs of Scenario B (b) Cost Comparison of the Direct Costs(Per Linear Foot)

5.4 Field Test II: Husband Street Project, Stillwater, Oklahoma

The project location for the second field test was the 4000 block of Husband Street on the South side of Stillwater, OK. The purpose of the bore was to install a drain line of septic systems for 4 houses as a part of a small housing development. A section of the gravity sewer line for this project was installed using the OnGrade^{TM} HDD method. The details of the job conditions are as follows:

a. Pipe material: HDPE DR11

b. Pipe diameter: 4 inch

c. Soil type: Sandstone rock with a 2-3 feet thick layer of clay soil on top

d. Grade: -1.25%

e. Depth of installation: 7.5 ft on the uphill end and approximately ground level (1 ft) on the downhill end

f. Length of sewer pipe installed with OnGrade^{TM} HDD method: 325 ft

g. HDD crew: 1 drilling rig operator, 1 tracker operator, 1 helper

Since it was required to install the sewer line 7.5 ft below the ground surface and due to the soil conditions present on the job-site the entire length of the sewer line had to be installed embedded within the layer of the sandstone rock. The procedure adopted to install the pipe using the OnGrade^{TM} HDD method was similar to the procedure and techniques described in Chapter 4. For this case study the JT3020 drilling unit manufactured by Ditch Witch was used to drill and maintain the grade when drilling in sandstone. The drilling bit used for the bore was a 5.5T́CI. The beacon was housed inside the drill head and was located at the 12 o'clock position on the tool. In order to record the depth readings during the pilot drilling process, the beacon was turned through toward the tracker (12 o'clock position, pointed toward tracker) in the calibration fixture. For calibrating the pitch reading during installation, the beacon housing was turned to the 3 o'clock position to get accurate readings. The process of installation of the gravity sewer line in the sandstone rock was a slow process. It required about 3 days to complete the project. The time required to complete the pilot bore for the 325 ft of the sewer line was approximately 9 hours. As the line was installed within the sandstone rock the rate of installation was approx 36 ft/hour which is lower when compared to the installation rate within soil such as clay.

As a part of the case study, an inspection was done to record the installed depth of the pipe as well as to check for the presence of any dips or rises in the installed sewer line. Figure 5.5 illustrates the internal inspection results.

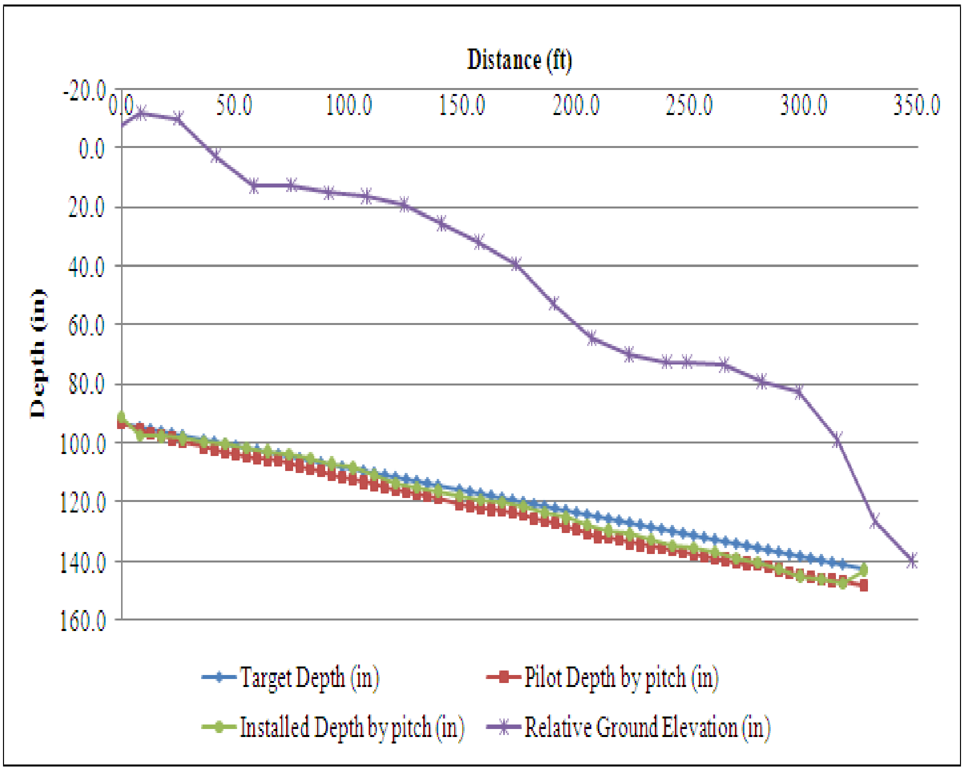


Figure 5.5: Bore Plot Showing Desired and Final Grade (Husband Street Project)

5.4.1 Cost Analysis

Similar to the analysis conducted for the Arbor Village Project, a cost comparison was done for the Husband Street Project using the data collected on the project job-site. Since the gravity sewer line was installed using OnGrade^{TM} HDD method, cost calculations were based on the actual data collected during execution of the project. The calculations of the open-cut method were based on the guidelines provided by the City of Stillwater for installing a 4 inch gravity sewer line.

Table 5.6: Direct Cost Calculations for Open-Cut Method

Work Item	**Unit**	**Unit Cost**	**Quantity**	**Total Cost ($)**
Mobilization & Demobilization	Ea	168.50	2.00	337.00
Pick-up truck 4-wheel drive	Ea	190.00	1.00	190.00
Excavation	C.Y	4.45	336.57	1,497.74
Bedding Material	C.Y	33.81	58.71	1,984.99
Compacting Backfill	C.Y	2.22	274.35	609.06
Total Cost				4618.78
Total Length of Installation	L.F			325.00
Cost per linear foot				14.21

The following assumptions were made for calculating the costs using the two methods for the case study:

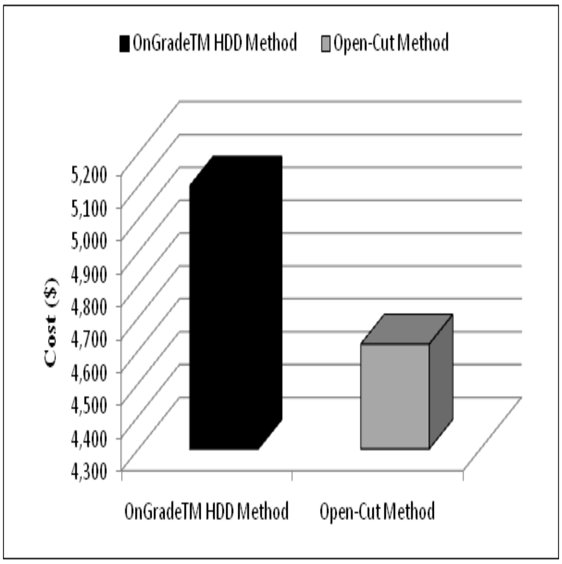
- The unit cost calculations for the OnGrade^{TM} HDD method are based on the ownership costs of the equipment like the drilling rig, tracking electronics, truck/trailer and the vacuum system.
- The calculation of the costs associated with the OnGrade^{TM} HDD method is based on actual equipment and labor hours measured on site.
- The material costs for sewer pipe has not been included.
- The cost calculations of the open-cut method are based on the quantity take-off done in accordance with the guidelines provided by the City of Stillwater and the OSHA Regulations (Standard Number 1926.652 (a) & (b)).

The gravity bore for this case-study was entirely within the property line of the construction project and did not require crossing any street, hence there were no social costs associated with this project. The direct cost calculations for the installation of

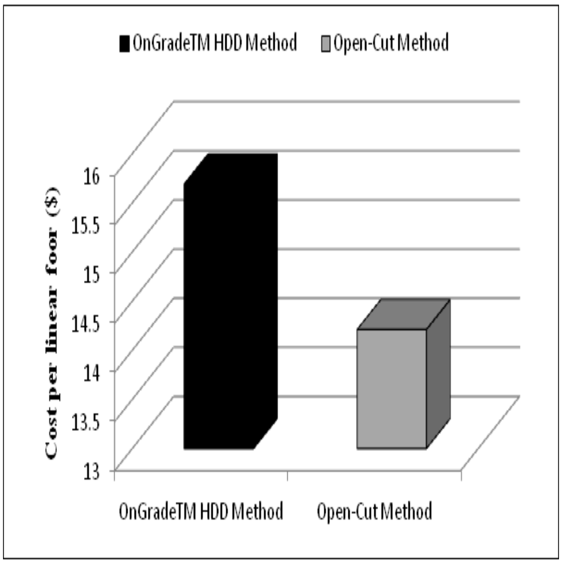
Table 5.7: Direct Cost Calculation for OnGrade^{TM} HDD Method

Work Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost ($)**
Drilling Unit & Tooling	Day	3.00	302.77	908.31
Tracking Electronics	Day	3.00	75.00	225.00
Truck/Trailer (includes fluid mixing system)	Day	3.00	132.68	398.04
Drilling Fluid Additives	Project			200.00
Vacuum System	Day	3.00	46.64	139.92
Maintenance	Day	3.00	94.63	283.89
Drill Operator	Day	3.00	200.00	600.00
Locator	Day	3.00	180.00	540.00
Helper	Day	3.00	160.00	480.00
Insurance	Day	3.00	135.00	405.00
Fuel	Day	3.00	150.00	450.00
Batteries	Day	3.00	20.00	60.00
Mobilization/ Demobilization	Project			300.00
Excavation	CY	24.72	4.45	110.00
Total Cost				5,100.16
Total Length Installed	L.F		325.00	
Cost Per Linear Foot				15.69

the gravity sewer line can be seen below. Table 5.6 shows the direct costs associated with this project if the gravity sewer line had been installed using the traditional open-cut method. Whereas, Table 5.7 shows the costs associated when using the OnGrade^{TM} HDD method. A summary of the costs associated with this project using either method of installation is provided in Figure 5.6. It can be noted that for the Husband Street Project the use of open-cut method on the job-site would reduce the costs incurred by the project by \$481.22 (.i.e \$1.48/lf).



(a)



(b)

Figure 5.6: (a) Cost Comparison of Direct Costs for Husband Street Project (b) Cost Comparison of the Direct Costs(Per Linear Foot)

5.5 Summary of Cost Comparison

From the two different case studies discussed above, it can be seen that OnGrade^{TM} HDD method is a competitive alternative to open-cut method. Figure 5.7 shows a summary of the costs associated with the different case studies and also the different scenarios. The use of HDD is a competitive method for the installations of the gravity sewer line in the Arbor Village Project. There is a vast reduction in the installation costs when using the OnGrade^{TM} HDD method. This reduction in cost

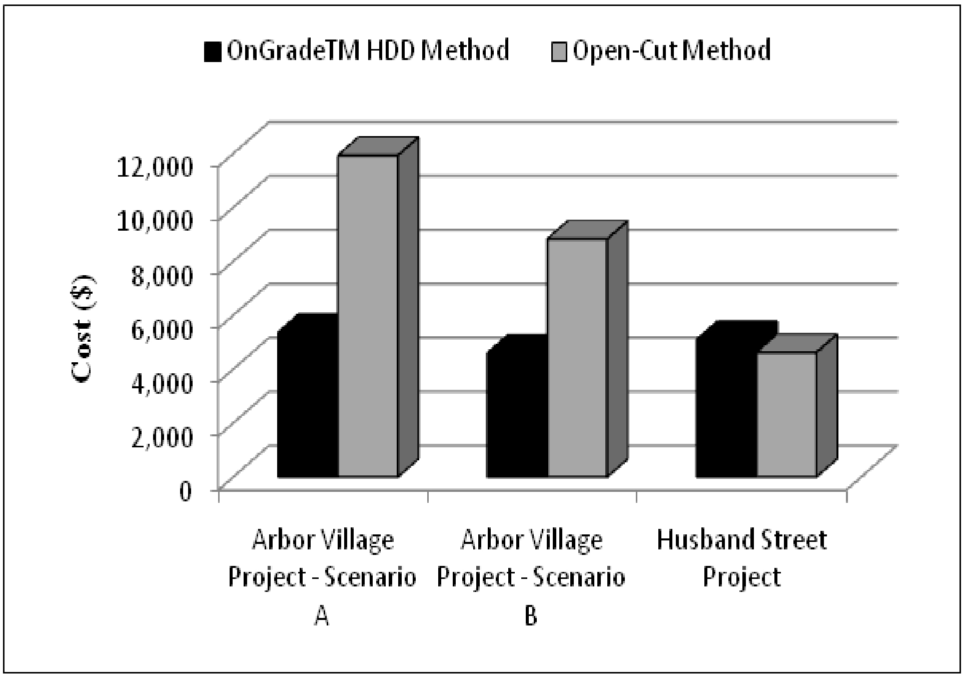


Figure 5.7: Cost Analysis of All the Case-Studies

can be attributed to the reduction of the excavation required, reduction in the amount of bedding/embeddment and compacting material/equipment required for installing the gravity sewer line. Whereas, in the second field test, i.e. the Husband Street Project it can be seen that the per linear foot costs associated with installing the gravity sewer line using OnGrade^{TM} HDD is \$15.69/lf and the per linear foot cost of installation when using the open-cut method is \$14.21/lf. In this case the use of the OnGrade^{TM} HDD method will result in an additional unit cost of \$1.48/lf.

Hence, it is of prime importance to clearly understand the factors which affect the applicability and the economic feasibility of using the OnGrade^{TM} HDD method. The next chapter will discuss in detail the factors which affect the suitability of using the OnGrade^{TM} HDD method.

CHAPTER 6

Assessment of Technical Capabilities of OnGrade^{TM} HDD

6.1 Introduction

This chapter consists of two main sections. The first section identifies and describes the technical boundary conditions which affect the selection and the applicability of the OnGrade^{TM} HDD method for the installation of gravity sewer lines. The second section of the chapter describes the formulation of an Excel based model developed for checking the applicability and the economic feasibility of using OnGrade^{TM} HDD method in comparison with the traditional open-cut method for installing a gravity sewer line.

6.2 Technical Boundary Conditions OnGrade^{TM} HDD

Based on the findings of the survey conducted, literature review and the field tests executed, four factors which affect the suitability of the OnGrade^{TM} HDD method for a gravity sewer line project were identified. These factors are as follows:

a. Grade of installation of pipe

b. Depth of installation of pipe

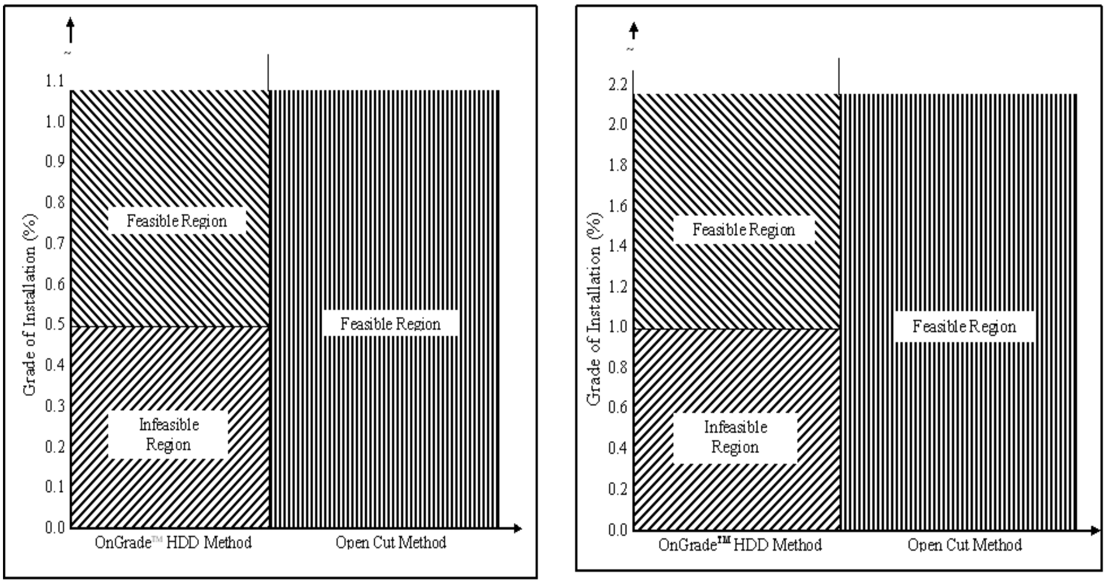
c. Soil conditions prevailing on the job-site

d. Number of connections/laterals connecting to pipe being installed

Each of the above factors affect the feasibility and the economic attractiveness associated with the use of the On-Grade HDD method for installing a gravity sewer line.

6.2.1 Grade of installation of pipe

When installing a gravity sewer line, it is of foremost importance to maintain the line and grade of the pipe being installed. The grade of installation of the gravity sewer line varies from project to project and also with the regulations provided by the municipality of the city. For instance, the City of Stillwater, Oklahoma requires



(a) (b)

Figure 6.1: (a) Boundary Conditions for Grade of Installation in Clay Soil. (b) Boundary Conditions for Grade of Installation in Rocky Soil

that a minimum grade of 0.4% be provided for any 8 inch gravity sewer line being laid. It is believed by many people in the industry that the traditional HDD method available can install gravity sewer lines with grades as flat as only 1% while successfully maintaining its line and grade. For most gravity sewer line projects with grades less than 1%, the traditional HDD is not a feasible method.

When using the OnGrade^{TM} HDD method for installing gravity sewer lines it is recommended that grades as flat as 0.5% can be installed in clay soils. Whereas, when installing in rocky soil grades of 1% or greater are preferred. Figure 6.1 (a) shows the feasible regions for installing a gravity sewer line in clay soil when using the OnGrade^{TM} HDD method and the traditional open-cut method. Whereas 6.1 (b) shows the feasible regions for installing a gravity sewer line in rocky soil when using either method of installation. These conclusions are based on several successful test bores and the field tests (discussed in the previous chapter) conducted using the OnGrade^{TM} HDD method. These constraints on the grades of installation are also based on the experience of the people in the industry who have worked with the OnGrade^{TM} HDD method.

6.2.2 Depth of installation of pipe

One of the limitations associated with the use of OnGrade^{TM} HDD method for installing gravity sewer lines is the depth at which the line is to be installed. The limitation associated with the minimum depth of installation is governed by the amount of soil cover present. In ideal conditions, it is preferred to have at least 3 feet (36 inches) of soil cover above the line being installed. A soil cover having a thickness less than 3 feet would result in a layer of soil with very little resistance to movement making it difficult to maneuver the drill head and maintain the line and grade of installation. This constraint associated with the OnGrade^{TM} HDD method of installation is attributed to surface heave mechanisms[14].

Whereas, the limitation associated with the maximum depth of installation is governed by the ability of the tracker to receive and interpret the information transmitted by the beacon located within the drill head. As the depth of installation increases the strength of the signal sent out by the beacon reduces. Thus the potential of error in tracking the line and grade of the pipe being installed increases. Based on the various test bores and field tests conducted using the OnGrade^{TM} HDD method it has been noted that the maximum depth of installation should not be greater than 30 feet. When installing a line at a depth greater than 30 feet it is difficult to be certain about the maintenance of the grade of the sewer line. The depth of installation is also governed by the soil conditions prevailing on the job-site. The affect of the different soil conditions on the depth of installation have been further discussed in the next section. Figure 6.2 shows the constraints related to the depth of installation of a gravity sewer line using the OnGrade^{TM} HDD method and the open-cut method.

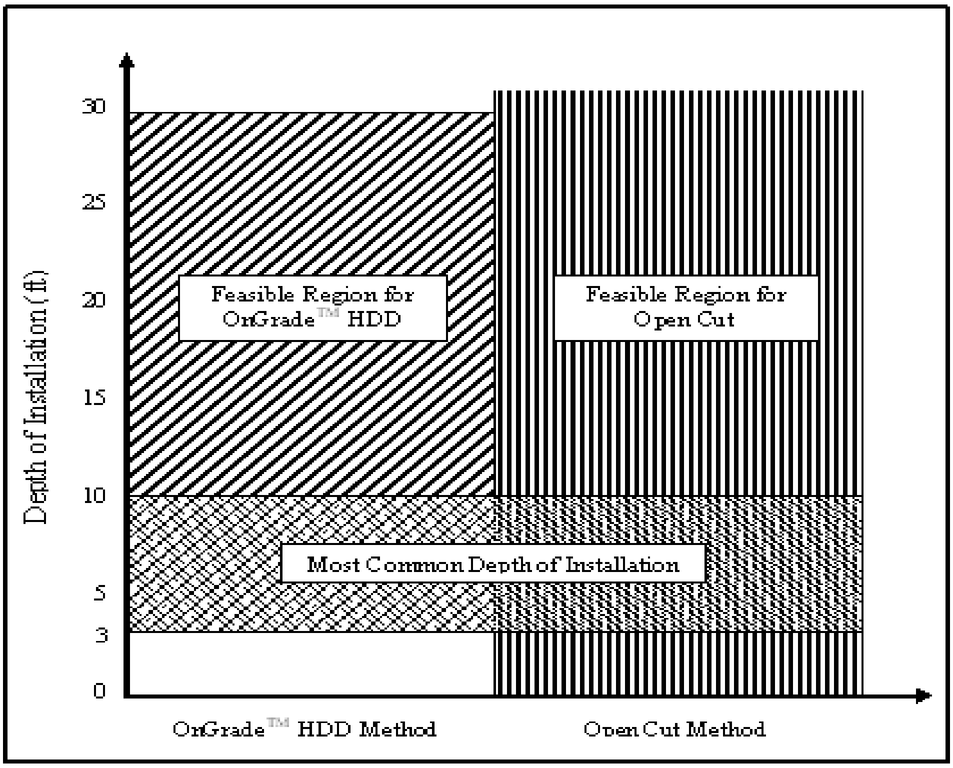


Figure 6.2: Boundary Conditions Associated with the Depth of Installation

There are certain cost implications of the depth of installation. Figure 6.3 shows the impact of the depth of installation on the cost incurred by the project. It can be seen in Figure 6.3 that the depth of installation does not significantly effect the cost incurred by a project when using the OnGrade^{TM} HDD method. This can be attributed to the fact that, an increase in the depth does not affect the rate of installation and hence the time required for the completion of the project. Whereas, when using the open-cut method, as the depth of installation increases the cost increases.

This is due to the increase in the time required for the excavation,the amount of excavation and a subsequent increase in the quantity of the bedding/compacting material required. Figure 6.3 shows that as the installation depth increases beyond 7ft, it is more economical to use the OnGrade^{TM} HDD method.

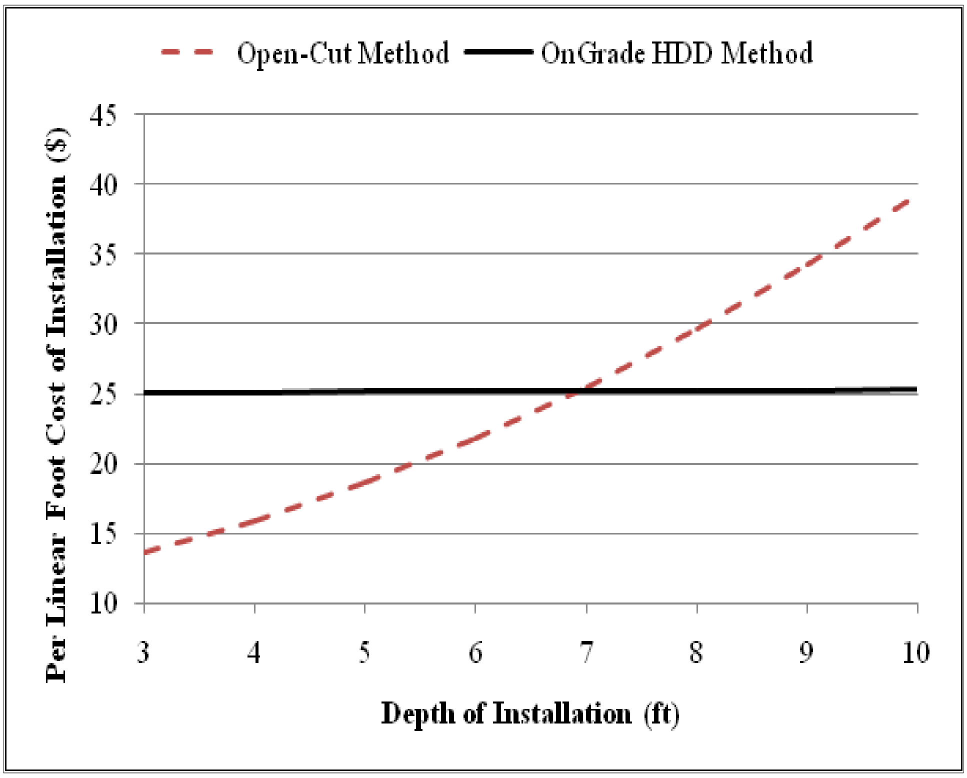


Figure 6.3: Cost Implications of the Depth of Installation in Clay Soil

6.2.3 Soil conditions prevailing on the job-site

Soil conditions present on the job-site greatly affect the applicability of the OnGrade^{TM} HDD method for installing the gravity sewer lines. Cohesive soil, for instance clay is considered to be an ideal material for installing a gravity sewer line. When installing a line in clay soil it is easier to control the drill head while drilling the pilot bore and hence maintain the line and grade of the pipe being installed. The rate of installation in clay soil that can be achieved by using OnGrade^{TM} HDD ranges from 55 - 60 lf/hr.

When drilling in non-cohesive soil, like sand a similar rate of installation of 55 -

60 lf/hr can be achieved. However, when drilling in sand, it is important to be above the water table, because when drilling below the water table, fluidization of the soil may occur and the pipe position may migrate within the ground. Also, when drilling in non-cohesive soil and below the water table, there is a high chance of borehole collapse when drilling and very little borehole stability can be achieved.

Whereas, when installing in rocky soil the rate of installation is fairly reduced to 30 - 36 lf/hr. This rate of installation and the accuracy attained when installing the line also depends on whether the rock present on the job-site is a layer or fractured. When installing a gravity sewer line, it is preferred to install in non-fractured rock. It is comparatively more difficult to maintain the line and grade when drilling in fractured rock since the chances of the drill head being thrown of the course increases.

It is also important to note that when installing a gravity sewer line in soils which have high electrical conductivity, there is a reduction in the maximum depth of installation. When using OnGrade^{TM} HDD method, it is essential that the tracker receives a strong signal from the beacon in order to interpret its precise location of the drill head below the ground. Soils with high electrical conductivity tend to absorb the signals thus reducing the strength of the signal being received by the tracker. This reduces the level of confidence of the grade being installed and also increases the possibility of errors. Figure 6.4 summarizes the different soil conditions which are suitable and unsuitable for the use of the OnGrade^{TM} HDD method and the open-cut method.

6.2.4 Number of connections/laterals connecting to pipe being installed

The number of connections required to be made to the pipe being installed significantly affect the economic feasibility of using the OnGrade^{TM} HDD method for installing a gravity sewer line. Any connection/lateral to the main line would require trenching open a section of the installed main line in order to make a connection

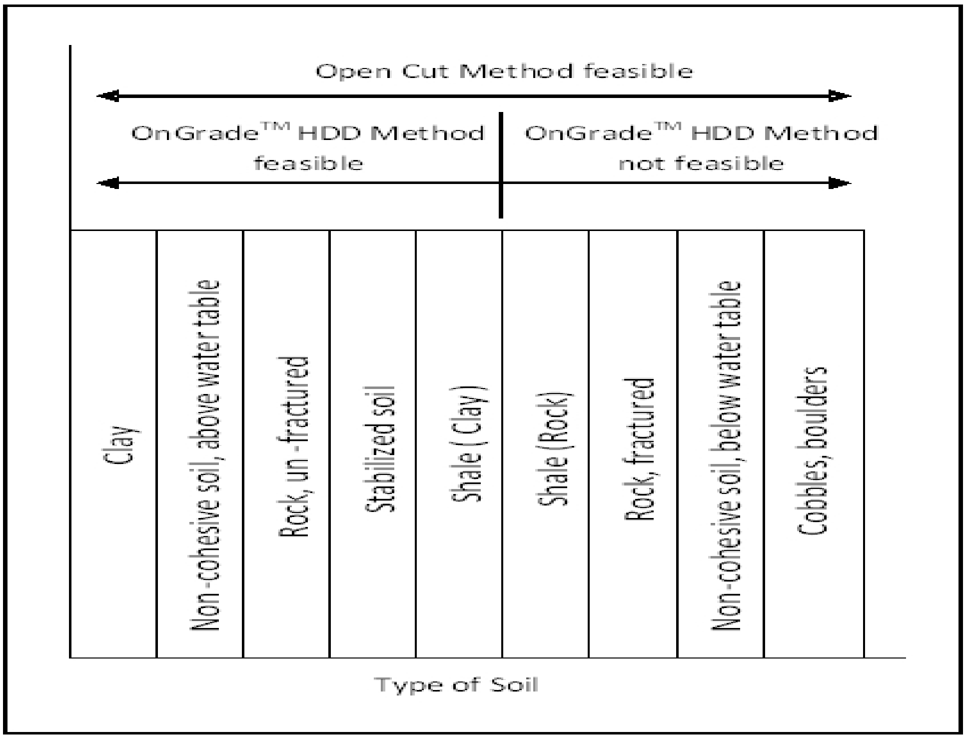


Figure 6.4: Soil Classification based on Suitability and Unsuitability

between the lateral and the main line. If the number of laterals along the length increases, the amount of trenching would increase linearly. Hence, installing a main line using the OnGrade^{TM} HDD method which requires connecting a large number of connections defers some of the advantages associated with the use of a trenchless method of installation. The main impact of the number of laterals connecting to the main line is seen on the costs associated with the project. Laterals for any project are generally installed at flatter grades when compared to the main line installed and at shallower depths. Hence, the laterals are generally installed using the open-cut method. To understand the effect on costs due to the number of laterals connecting to an installed sewer line, using either method of installation, two different scenarios are discussed below.

- Scenario I: The main sewer line is installed using OnGrade^{TM} HDD method and the laterals connecting to the main line are installed using the traditional open-cut method.

- Scenario II: The main sewer line and the laterals connecting to the main line have been installed using the open-cut method.

For the purpose of calculations the following assumptions are made:

a. The main line installed is assumed to have a length of 400 ft and and 8 inch diameter.

b. The average depth of installation for installation of the main line is considered to be 7ft.

c. The length of the laterals is assumed to be 100 ft.

d. The soil type is assumed to be clay.

Table 6.1 shows the cost calculations for installing a gravity sewer line in clay soil of length 400 ft and at an average depth of 7 ft. Also, Table 6.2 shows the cost of installing laterals connecting to the main line when both the main line and the lateral are installed using the open-cut method. Whereas, Table 6.3 shows the cost incurred while installing the lateral using the open-cut method when the main line has been installed using the OnGrade^{TM} HDD method. Whereas the cost of installing the main gravity sewer line using the OnGrade^{TM} HDD method was interpolated using the cost calculation done for the Arbor Village Project. The costs shown below in the tables has been used to develop the 6.5 to determine the break-even point associated with the installation of the laterals.

A comparative analysis of the total costs of installing the main sewer line and the laterals using both the installation methods was performed. This cost was calculated by adding the cost of installation of the main sewer line using either method of installation with the cost of installing the lateral using the traditional open-cut method. The results obtained have been summarized in the Figure 6.5.

Table 6.1: Cost Calculations for Installing Gravity Sewer Line using the Open-Cut Method

Work Item	Unit	Unit Cost	Quantity	Total Cost
Mobilization & Demobilization	Ea	168.50	2.00	337.00
Pick-up truck 4-wheel drive	Ea	190.00	1.00	190.00
Excavation	C.Y	4.45	1002.81	4462.50
Bedding Material	C.Y	33.81	91.39	3089.90
Compacting Backfill	C.Y	2.22	769.30	1707.85
Dewatering	Day	115.50	3.50	404.25
Total Cost				10191.50
Total Length of Installation	L.F			400.00
Cost per linear foot				**25.48**

Table 6.2: Cost Calculations for Installing Lateral & Main Line using the Open-Cut Method

Work Item	Unit	Unit Cost	Quantity	Total Cost
Excavation	C.Y	4.45	32.93	146.54
Bedding Material	C.Y	33.81	9.31	314.77
Compacting Backfill	C.Y	2.22	18.24	40.49
Dewatering	Day	115.50	1.00	115.50
Total Cost				617.30
Total Length of Installation	L.F			100.00
Cost per linear foot				**6.17**

It is seen in Figure 6.5 that the use of OnGrade^{TM} HDD method for installing the main gravity sewer line continues to remain economical as long as the number of

Table 6.3: Cost Calculations for Installing Laterals using the Open-Cut Method when Main Line is Installed using OnGrade^{TM} HDD Method

Work Item	**Unit**	**Unit Cost**	**Quantity**	**Total Cost**
Excavation	C.Y	4.45	40.53	180.36
Bedding Material	C.Y	33.81	9.31	314.77
Compacting Backfill	C.Y	2.22	18.24	40.49
Dewatering	Day	115.50	1.00	115.50
Total Cost				651.12
Total Length of Installation	L.F			100.00
Cost per linear foot				**6.51**

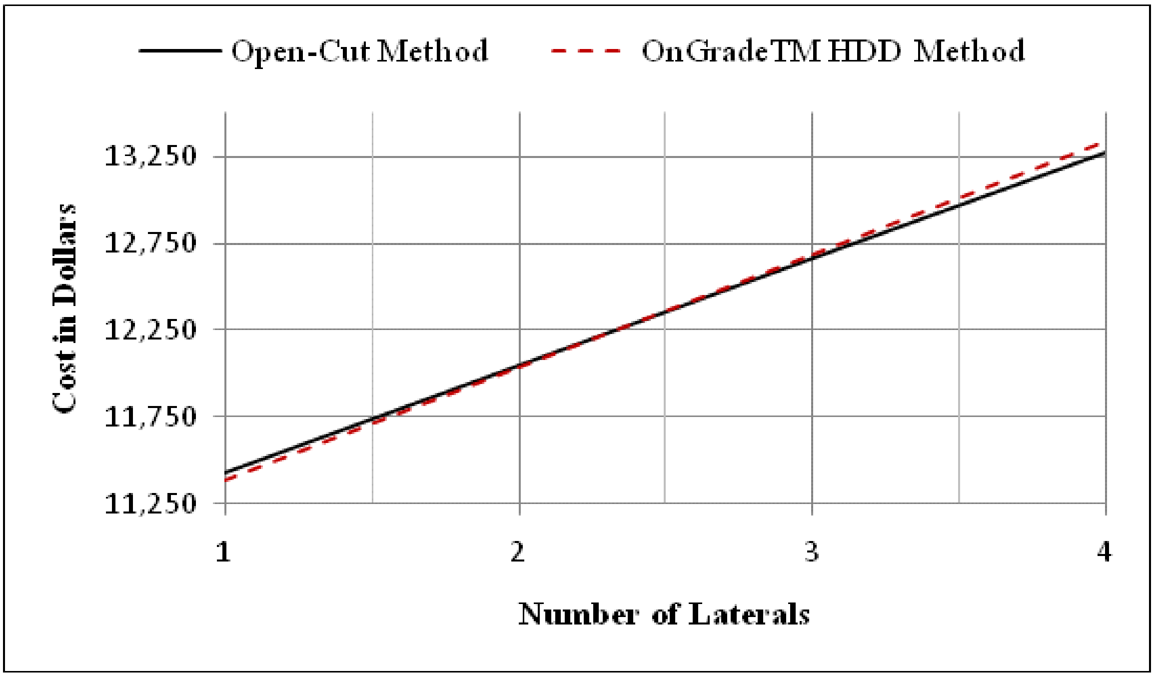


Figure 6.5: Break-even Point for Installation of Laterals

laterals required to be installed is two or less than two. As the number of laterals to be installed increases, the cost effectiveness achieved by using the OnGrade^{TM} HDD method for installing the main sewer line is deferred. Hence, when making a decision about the method to be chosen for installing the gravity sewer line and the laterals connecting to it, it is very important to consider the number of laterals required to be installed and their effects on the cost of installation.

6.3 Development of OnGrade^{TM} HDD Method Suitability Analysis Model

This section discusses a decision support system which is formulated to facilitate the decision making process of selecting the method for installing a gravity sewer line. This system is developed using Microsoft Excel 2007. The system consists of two sections: an input section and an output section. The input section of the model requires the user to enter the project information. Based on the input provided by the user, the output section of the model provides the user with the results of a basic suitability check of the OnGrade^{TM} HDD method for the particular project.

This decision support system (DSS) checks the suitability of the OnGrade^{TM} HDD method for a project based on five factors. These factors, including grade of installation, pipe diameter, depth of installation, soil conditions prevailing on job-site and, number of laterals connecting to the main line being installed.

6.3.1 Input Section - Front End of the Model

The input section of the model consists of two main parts. Figure 6.6 shows a screen shot of the input screen of the DSS model. The first part - 'Project Details' of the model allows the user to enter the basic project details such as the name of the project, the project location and the date. The second part - 'OnGrade^{TM} HDD Suitability Evaluation' consists of the five factors discussed earlier, which affect the suitability of the OnGrade^{TM} HDD method for a particular project. Each factor listed in the model has a drop-down menu which can be seen in Figure 6.7. The user can select an option from the drop-down menu for each of the five factors. It

Feasibility Check for On-Grade HDD Method: Installing Gravity Sewer Line		
Project Details:		
Project Name:		
Project Location:		
County:		
Date:		
On-Grade HDD Suitability Evaluation:		
Factor 1:	Grade of Installation	
Factor 2:	Pipe Diameter	
Factor 3:	Depth of Installation	
Factor 4:	Soil Condition	
Factor 5:	Number of Laterals	

Figure 6.6: Screenshot of the DSS Model

is important that while making this selection the user selects an option which best describes the project site conditions. After the user fills in all the project details and

On-Grade HDD Suitability Evaluation:		
Factor 1:	Grade of Installation	Greater than 0.5%
Factor 2:	Pipe Diameter	Less than 16 inches
Factor 3:	Depth of Installation	Less than 30 ft
Factor 4:	Soil Condition	Non-Cohesive Soil - Sand, Above water table
Factor 5:	Number of Latera	

Cohesive Soils - Clay
Non-Cohesive Soil - Sand, Below water table
Non-Cohesive Soil - Sand, Above water table
Rock - Fractured
Rock - Un-fractured
Soil with cobbles, boulders and obstructions

Figure 6.7: Screenshot of the OnGrade^{TM} HDD Suitability Evaluation Input Screen

makes the appropriate selections using the drop down menus provided for each of the five factors, the user can check the results obtained based on their input. The Figure 6.8 gives a schematic representation of the algorithm associated with the decision making process. It provides an overview of the decision making process adopted by

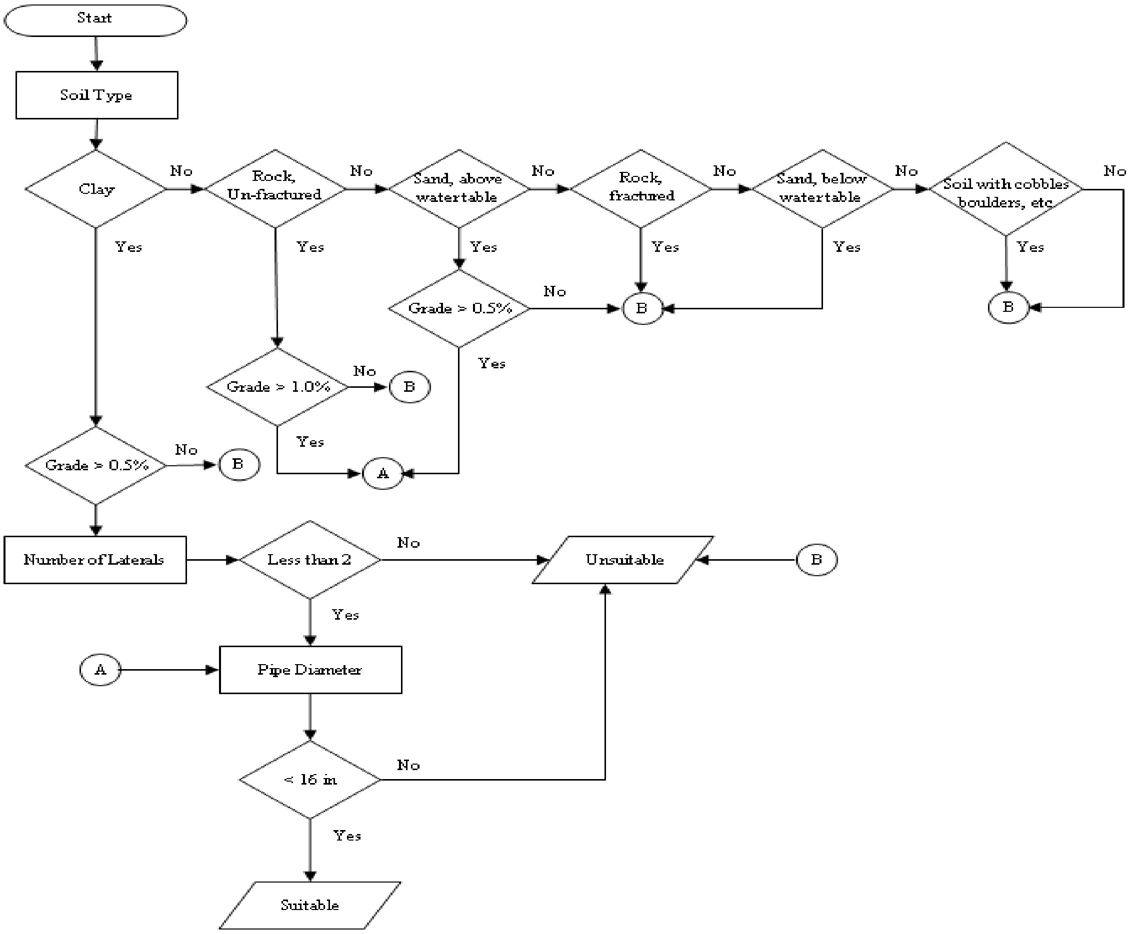


Figure 6.8: Flowchart for the Decision Support System

the Decision Support System to analyze the input data and provide the user with a feasibility result. Any user trying to perform a feasibility check should be able to utilize this chart and the accompanying decision support system to check the viability of the OnGrade^{TM} HDD method for a particular project.

6.3.2 Output Section - Back End of the Model

The output can be viewed in the feasibility results tab of the same Excel document. Figure 6.9 shows a screenshot of the output given by the model. As seen in Figure

Feasibility Check Results for On-Grade HDD Method: Installing Gravity Sewer Line			
Project Details:			
Project Name:	0		
Project Location:	0		
County:	0		
Date:	3/10/2009		
On-Grade HDD Method Suitability Evaluation Results			
Factor		**Option Selected**	**Result**
Factor 1:	Grade of Installation	Greater than 0.5% (Clay Soil)	Suitable
Factor 2:	Pipe Diameter	Less than 16 inches	Suitable
Factor 3:	Depth of Installation	Greater than 30 ft	Unsuitable
Factor 4:	Soil Condition	Cohesive Soils - Clay	Suitable-Approx. Rate of Installation 60lf/hr
Factor 5:	Number of Laterals	Less than or equal to 2 laterals each of length 100 ft	Suitable

Figure 6.9: Screenshot of the OnGrade^{TM} HDD Suitability Evaluation Results

6.9 the output section also consists of two parts. The first part displays the project details entered by the user in the input section. The second part of the output provided by the model lists the five deciding factors, the choices made by the user and also provides the result of suitability or unsuitability of the use of OnGrade^{TM} HDD based on the input.

For instance, if the grade of installation for a project was 1.25% in clay soil. In that case the user would select the option 'Grade of Installation - Greater than 0.5% (Clay Soil). The output provided by the model is that the OnGrade^{TM} HDD method is a 'Suitable' option for installing the gravity sewer line. Whereas, if the user then selected that the 'Depth of Installation - Greater than 30 ft', then the model would give an output indicating that the OnGrade^{TM} HDD method would be 'Unsuitable' for the same project.

As discussed earlier, the 'OnGrade^{TM} HDD Method Suitability Evaluation Results' consists of three columns - the first column indicates the factors affecting the decision making, the second column indicates the choice made by the user and the third column indicates the result provided by the model. The output results provided by the model for every factor is either Suitable or Unsuitable. When the results obtained from the DSS model for each factor is suitable, it indicates that the OnGrade^{TM} HDD method is a viable option for the project. Whereas, in a scenario that either one of the factors has an output result of unsuitable, then the user should check the site conditions once again and identify the corresponding factor/factors. If the unsuitability is a result of either the soil conditions prevailing on the job-site or the number of laterals connecting to the line being installed, the user should delve further into the information at hand and check the viability of the OnGrade^{TM} HDD method for the project. Whereas, if the unsuitability is a result of the grade of installation or the depth of installation, the user might want to consider other methods of installation for the project under consideration.

It is important to remember that this model has been created based on the data collected from the field tests conducted as a part of this study. The facts and figures provided here may vary to an extent based on an individual project site conditions. The intent of this model is to provide its users with a consolidated means to identify the suitability of the OnGrade^{TM} HDD method for a project.

CHAPTER 7

CONCLUSIONS

7.1 Summary

This work puts forth a hypothesis that OnGrade^{TM} HDD method is a viable option for projects which currently use open-cut method for the installation of gravity sewer lines. A survey was conducted to understand the perceptions of the people in the industry regarding this topic. Two field tests were also conducted to collect data to analyze the hypothesis and substantiate it. This chapter will summarize the findings of this study based on the survey and the field tests conducted.

Out of the responses received to the survey questionnaire it was noted that 83.33% of the people had prior experience with using the traditional HDD method for installing gravity sewer lines. The main advantages of using HDD for installing gravity sewer lines in comparison to the open-cut method were identified as the reduction in the restoration costs, reduction in the costs associated with the import of backfill and pipe bedding material and the ability to install utilities in environmentally sensitive areas. Whereas, the limitations were identified as the number of lateral connections to the line being installed, problems maintaining the line and grade, and the different soil conditions prevailing on the job-site which affected the successful completion of a project. It was noted that many people in the industry have used HDD as an option for installing gravity sewer lines due to the several benefits it has to offer. Also, the 16.67% people who have still not used HDD on a project for installing gravity sewer lines are aware of the method and its applications but are not confident about its suitability for their projects as well as its ability to maintain the critical line and grade.

In order to support the applicability of the OnGrade^{TM} HDD method this study provides an analysis of the two field tests conducted. Figure 5.7 shows a comparison of the costs of using the OnGrade^{TM} HDD method and the open-cut method for the two field tests. The figure shows that the costs associated with the use of the OnGrade^{TM} HDD method are comparatively low when compared to the costs associated with open-cut method for the Arbor Village Project. Whereas, a comparison of the costs associated with the two methods for the second field test the Husband Street Project, it can be seen that the per linear foot costs associated with the OnGrade^{TM} HDD method are higher as compared to the traditional open-cut method.

These differences in costs can be attributed to various different factors. For instance, the depth of the gravity sewer line installed for the Arbor Village Project (Scenario B) ranged from 7.91ft to 9.13 lf and the project required the installation of a 8 inch line. Whereas, for the Husband Street Project, the depths of installation ranged from 7.5 ft to ground level and the diameter of the pipe to be installed was 4 inches. Hence, when using the open-cut method of installation, the cubic yard excavation associated with the Arbor Village Project is more as compared to the Husband Street Project. This in turn increases the cost of the bedding/embeddment material and also the compaction costs for the Arbor Village Project. Thus the use of the OnGrade^{TM} HDD method for the Arbor Village Project proves to be more economically competitive than for the Husband Street Project.

Also an analysis was done to estimate the cost of installation using the OnGrade^{TM} HDD and the open-cut method. Direct and indirect costs associated with the projects were identified and used for this estimation. The cost of vehicular and the traffic disruption was identified as a major contributor to the social cost associated with a project. These costs significantly increase the final cost estimate of a project. These social costs can be deferred when using the OnGrade^{TM} HDD method. Considering an estimate of the social costs helps give a better idea of the affect of social costs on the overall costs of a project when using either method of installation.

This study has also helped marked and identify the boundary conditions for the successful use of the OnGrade^{TM} HDD method. Five such factors were identified and their effects were described in detail in Chapter 6. These factors help get a better understanding of the boundary conditions associated with this method. It is important that these factors be considered and analyzed during the decision making process about the method of installation to be used.

During the course of this research the major problem encountered was to be able to find contributors who could provide us with the unit costs associated with the use of the OnGrade^{TM} HDD method. Due to the recent advent of this method, standardized costs were unavailable. For instance, for calculating the costs of installation using the open-cut method, the R. S Means Cost Guide was a standardized reference. But for obtaining the unit costs associated with the installation of a gravity sewer line using the OnGrade^{TM} HDD, there was a need to rely on a few industry sources, who had prior experience with this method of installation.

7.2 Recommendations for Future Work

The limitations/shortcomings of this study are associated with the finite information and resources available when calculating the costs of installation using the OnGrade^{TM} HDD method. Also the costs of the pipe materials used with either method of installation were not considered in this study. To overcome these weaknesses, the following recommendations are proposed:

a. It was determined in the earlier chapters that it is very important to understand the effects of different soil conditions on the applicability of the OnGrade^{TM} HDD method for a project. The findings of this study have been based on the two field tests conducted. Hence it would be recommended that further studies conducted in this area should include conducting a larger set of field tests with different project conditions. This would enable a better understanding of the advantages and the limitations of using this method over the open-cut method.

b. This study compares the OnGrade^{TM} HDD method to the open-cut method in terms of economic feasibility and the applicability to various projects. There are several other trenchless methods of installation such as Auger Boring, Micro-tunneling and Pilot Tube Method. These methods are currently being used for line and grade installations, either on their own or in combination with open-cut method. It is necessary to compare the competitiveness of the OnGrade^{TM} HDD to these other trenchless methods of installations, in order to be able to make a well informed decision.

c. It is known that the number of connections/laterals to the main line is a crucial factor which needs consideration when using the OnGrade^{TM} HDD method. It is recommended that further field tests be conducted which involve the installation of the main line and the laterals/connections of varied lengths and at different depths.

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APPENDIX A

SURVEY QUESTIONNAIRE

1. Provide Company Name:
2. Prior experience of HDD for on-grade sewer construction: ☐ Yes ☐ No
3. Prior experience of Open Cut Method for on-grade sewer construction: ☐ Yes ☐ No
4. In your opinion does HDD have advantages over Open-Cut Method for on-grade sewer construction: ☐ Yes ☐ Don't know
5. In choosing between HDD and Open Cut Method for the construction of an On-grade sewer pipe, please rate the following advantages of HDD when compared to Open-cut method for a project:

Advantages	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Shortens project schedule	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. Reduces restoration costs	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Reduces construction footprint & impact	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
d. Increases site safety	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
e. Can be used in environmentally sensitive areas	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
f. Reduction in import backfill and pipe bedding	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

6. In your opinion, what are the limitations of HDD Methodology in comparison to Open-Cut method for on-grade sewer pipe construction (please rate each factor):

Limitations	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Maintaining the line and grade	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. Accidentally damaging other underground utility lines	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Number of connections	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
d. Soil conditions	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
e. Pipe material	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
f. Pipe diameter	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
g. Depth of burial of pipe	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

7. If you feel that pipe material affects the accuracy achieved during the construction, please rate the different pipe materials based on their suitability for construction of On-grade sewer projects using Horizontal Directional Drilling.

Types of Pipe	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Fusible Polyvinyl Chloride Pipe (PVC)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. High Density Polyethylene Pipe (HDPE)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Ductile Iron Pipe (DIP)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
d. Polymer Concrete Pipe (PC)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
e. Restrained Joint PVC	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

8. If you feel that maintaining the line and grade of the drilling rig is an important limitation in the use of HDD for On-grade sewer construction, please rate the following reasons:

Factors affecting line & grade maintenance	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. Lack of HDD tracking electronics to measure grades less than 1%	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. Locator giving inaccurate reading's due to influence of surrounding objects on site	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Steering difficulties due to presence of unexpected soil conditions	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
d. Product pipe not suitable for the grades required	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
e. Not feasible for all types of soils	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
f. Inability to maintain grade line during back-reaming/pullback of pipe material	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9. Please rate the different types of soils, in terms of their suitability for the use of HDD for On-Grade sewer construction:

Types of Soil	1=Unsuitable, 3=Neutral and 5=Suitable
a. Soft to very soft clay	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. Medium to hard clay	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Medium to dense sands (below water table)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
d. Medium to dense sands (above water table)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
e. Gravels and Cobbles less than 2 to 4inches	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
f. Soil with significant cobbles, boulders	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

10. In your opinion, what are the reasons due to which HDD has limited use in the installation of gravity flow sewer conduits (please rate each factor):

Reasons for limited use	1=Strongly Disagree, 3= Neutral & 5=Strongly Agree
a. People who operate & plan construction of gravity sewer systems are unaware of the applicability of the HDD technology for their projects	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. Professionals who are aware of HDD On-grade, do not believe that the equipment available is capable of installing pipes at critical grades	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. Professionals who are aware of HDD technology generally believe that HDD contractors lack the training, patience, or skill to successfully install On-grade sewers by directional drilling	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

11. Please provide additional comments regarding HDD for the construction of On-grade sewer lines in the space here:

12. May we contact you again?

Name: Phone: Ext:

13. Email:

14. Could you please provide us with the name and a contact point for the municipalities that you have worked with, for gravity sewer pipe line construction project, using horizontal directional drilling:

Name of City: Contact Person Name:

Phone: Ext:

VITA

Reeti R. Burman

Candidate for the Degree of

Master of Science

Thesis: PERFORMANCE ASSESSMENT OF ONGRADE^{TM} HORIZONTAL DIRECTIONAL DRILLING METHOD

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Bangalore, Karnataka, India on February 24^{th}, 1984.

Education: Received Bachelor of Science degree in Civil Engineering from Mumbai University in June 2007. Also, completed the requirements for the Degree of Master of Science at the Civil and Environmental Engineering Department at Oklahoma State University in May 2009

Name: Reeti R. Burman Date of Degree: May, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: PERFORMANCE ASSESSMENT OF ONGRADE^{TM} HORIZONTAL DIRECTIONAL DRILLING METHOD

Pages in Study: 77 Candidate for the Degree of Master of Science

Major Field: Civil Engineering

Horizontal Directional Drilling (HDD) has been widely accepted and used for installing gas and water lines, telecommunication cables, etc. However, one area where HDD has been used with only limited success is in the installation of gravity flow sewer lines. One primary reason is the difficulty with maintaining critical grades essential for gravity-flow sewer systems when using that conventional HDD tracking methods. Recently, advancements made in tracking systems, electronics, and operational techniques have made HDD technology a technically feasible and an economically attractive method for installing on-grade underground pipes in many situations. The newly developed technology illustrated in U.S. Patent 7,510,029 is one of representative techniques for accurate identification and tracking of the vertical location of drilling head. This study evaluates technical capabilities and the economic feasibilities of this new OnGrade^{TM} HDD HDD technology using actual project data. The accuracy in grade of installed pipe, soil conditions along with the operational cost, user cost information associated with the project are compared to the open-cut method.

ADVISOR'S APPROVAL: Dr. Hyunseok (David) Jeong